# ASSESSMENT OF RAPTOR MIGRATION CORRIDORS IN THE UNITED STATES

By

Laura McHugh

---



A Thesis Submitted to the Faculty of the

SCHOOL OF NATURAL RESOURCES AND THE ENVIRONMENT

In Partial Fulfillment of the Requirements

For the Degree of

MASTER OF SCIENCE

WITH A MAJOR IN NATURAL RESOURCES

In the Graduate College

THE UNIVERSITY OF ARIZONA

2017

STATEMENT BY AUTHOR

The thesis titled Assessment of Raptor Migration Corridors in the United States, prepared by Laura J. McHugh, has been submitted in partial fulfillment of requirements for a master's degree at the University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.



SIGNED: Laura J. McHugh

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

__________________________________ 3 August 2017

*R. William Mannan* Date

*Professor, Wildlife-Fisheries Science*

ACKNOWLEDGMENTS

This project would not have been possible without the help of many people. Firstly, I would like to thank my Thesis advisor, R. William Mannan, for his guidance both in the field and throughout my entire graduate program. I would like to thank my field technician, Kevin Krutzsch, for his dedication to fieldwork throughout the entire course of the study. Gabriella Furr for her help in the field and Timothy McHugh, for his support during data collection. I would like to thank Kyle Hartfield for his continual support and the countless hours of help he provided. Andrew Honaman for use of ART Lab resources and guidance. In addition, Wim van Leeuwen for use of ARSC resources. Thank you to my thesis committee members, John Koprowski and Craig Wissler, for their suggestions and support. A special thank you to my family and friends for their endless support and encouragement.

This project was made possible by Arizona Game & Fish's Heritage Fund grant. Additional funding was provided T&E Incorporated's Grants for Conservation Research.

**Table of Contents**

**Abstract**

Of the 36 diurnal raptor species in North America, 31 (~86%) are either complete or partial migrants. During fall and spring, raptors use “leading lines” or topographic features, such as mountain ranges, rivers, and coastlines that help guide them during their migration, and sometimes are redirected by diversion lines, or barriers that they are hesitant to cross (e.g., large bodies of water). Our objective was to assess the use of mountain ranges and rivers in central and southeastern Arizona by migrating raptors and to determine physical and ecological factors that are important to raptor migration across the United States. We counted migrating raptors in the spring and fall for two years at ten paired count stations in central and southeastern Arizona. Arizona counts were incorporated with counts from across the United States to determine physical and ecological features that influence migration rates. Raptor counts for central and southeastern Arizona averaged 2.0 raptors/hour, and were similar to what is observed at most other counting stations in the Central and Pacific Flyways. Stepwise regression models for the United States indicated counts were negatively related to distance from a diversion barrier and positively related to continuity of elevation. Understanding the factors that influence migrating raptors will inform decisions about environmental modifications and their potential influence on raptor populations.

The following appendices are written and formatted to be submitted to journals. Although part of a thesis, they are written in plural to reflect the necessary authorship for journal submission. The first appendix, titled “Assessment of raptor migration corridors in central and southeastern Arizona”, will be submitted to the Southwestern Naturalist. The second appendix, title “Assessment of raptor migration corridors in the United States”, will be submitted to the Journal of Raptor Research.

**Appendix I. Assessment of raptor migration corridors in central and southeastern Arizona**

1.1 Abstract

Raptors use leading lines to help guide their migration to and from wintering and breeding grounds in fall and spring. Mountain ranges are often leading lines because they create updrafts and thermals, and rivers provide visual pathways. Our objective was to assess the use of mountains and rivers in central and southeastern Arizona by migrating raptors. We counted migrating raptors in the spring and fall for two years at ten paired counting stations (eight pairs of stations were in mountains with one station of each pair located as high as possible given road access and the other in the valley; two paired stations were along rivers with one station located on the river and the other away from the river). Counts at each pair were conducted simultaneously and began two hours after sunrise and continued for five consecutive hours. During 577.5 observation hours, 1,139 raptors were counted (2.0 raptors/hour). Counts of raptors at high mountain stations were slightly higher ($\bar{x}$ = 3.09/hour; $s$ = 2.64) than counts at low stations ($\bar{x}$ = 2.0/hour; $s$ = 2.43; $P$ = 0.15) in fall, but not in spring (high sites, $\bar{x}$ = 1.5; $s$ = 2.07; low sites, $\bar{x}$ = 1.4; $s$ = 1.41; $P$ = 0.81). Number of raptors observed per hour at on- versus off-river stations did not differ in fall (fall on-river, $\bar{x}$ = 2.9; $s$ = 2.77; fall off-river, $\bar{x}$ = 1.5; $s$ = 1.28; $P$ = 0.32), but counts at on-river stations were higher than off-river stations during spring (spring on-river, $\bar{x}$ = 1.4; $s$ = 0.87; spring off-river, $\bar{x}$ = 0.3; $s$ = 0.53; $P$ = 0.03). The numbers of migrating raptors we counted are comparable to counts of raptors during migration in other sites in the west, which range from 2.0 to 77.3 raptors/hour, but low compared to many counts across the United States (2.0 to 696.0 raptors/hour). Our data suggest the mountain ranges and rivers in central and southeastern Arizona are not significant migration pathways for raptors.

## 1.2 Introduction

During fall and spring migration, raptors are known to use linear topographic features, called leading lines, which help guide their movements (Mueller and Berger 1967). Raptors use visual cues when migrating (Klaassen et al. 2010), unlike other avian species that use magnetic fields and celestial bodies (Wiltschko et al. 1998, Wiltschko and Wiltschko 2005). Directional mountain ranges are often used by raptors during migration because winds perpendicular to the ranges create updrafts that reduce the need for flapping and save energy (Thomas et al. 2011). Thermals, a type of updraft resulting from differential heating of the ground, also help raptors maintain altitude while expending less energy (Koch 2006). The mountain ranges in central and southeastern Arizona are situated between the Pacific and Central flyways (Hoffman et al. 2002), and could be a migration corridor for migrating raptors. North-south oriented rivers serve as leading lines for migrating raptors throughout the United States (Stout et al. 2009), and the two major rivers in southeastern Arizona could also serve to guide migration.

Climatic variables, such as temperature, wind direction, wind speed, and barometric pressure, also influence raptor migration. During fall migration, increased passage rates by raptors are seen following a cold front (Allen et al. 1996), and migration rates may be suppressed in the days leading up the passage of a cold front (Miller et al. 2011). Increased passage rates also are associated with increasing temperature and barometric pressure because of thermal generation (Hall et al. 1992, Miller et al. 2011).

Information about whether the mountain ranges and major rivers in central and southeastern Arizona are significant migratory pathways for raptors is limited. If raptors use leading lines during migration, a higher concentration of raptors would be expected to migrate over mountain ranges than over valley floors. Higher concentrations of migrating raptors also would be expected over Arizona's major rivers than away from rivers. Our objective was to count raptors in the mountain ranges and along rivers of central and southeastern Arizona to assess their relative use by migrating raptors in the fall and spring, and to assess how daily weather conditions influenced daily raptor counts.

## 1.3 Study Sites

For this study, we defined central and southeastern Arizona from 35° N to 31° N, and 110° W to 113° W. The area is comprised of a series of northwest to southeast oriented mountain ranges, with intervening valleys (Bahre and Shelton 1993). Part of the Sonoran desert, vegetation types range from desert, grassland, pinyon-juniper oak, pine-oak, and mixed conifer, depending on elevation (Hirt 1989). There are also two major north-south oriented rivers in southeastern Arizona, the San Pedro and the Santa Cruz. These perennial rivers are dominated by riparian vegetation (*Populus*, *Salix*, and *Prosopis* species), desert scrub, and semi-desert grassland (Stromberg et al. 1996, Morehouse et al. 2000).

## 1.4 Methods

We counted raptors at eight paired counting stations in the Bradshaw Mountains, Pinal Mountains, Piñaleno Mountains, Chiricahua Mountains, Dragoon Mountains, and Mule Mountains (Figure 1, Table 1). These mountain ranges form a potential corridor that is oriented southeast from Prescott, Arizona to Douglas, Arizona, and approximately 400 km in length. We also counted raptors at paired counting stations along the San Pedro and the Santa Cruz Rivers, both of which run from south to north in southern Arizona. Paired mountain stations consisted of one at a high elevation point (>1828 m), accessible by road, with a clear view overhead, and one at a low elevation point (<1828 m) on the valley floor (also accessible by road). Paired river stations consisted of one along the major river and another between 3-7 km away from the river to prevent the observer at each of the counting stations from observing the same raptors.

Counts at each pair of stations were conducted simultaneously by two or more observers, began two hours after sunrise, and continued for 5 consecutive hours (Niles et al. 1996, Thomas et al. 2011). We did not conduct counts during weather conditions that reduced visibility to less than approximately two kilometers (these type of conditions occurred only once and reduced one count period by 1.25 hours). Raptors flying over-head were identified to species when possible, and genera when species identification was difficult (Seeland and Niemi 2012). For each raptor observed, we recorded time and direction from the observer when it was first seen, and estimated and recorded flight direction, flight altitude, and distance from observer. Some raptors circled while generally moving in a particular direction and it was common to lose sight of them during these movements. To reduce counting the same individual more than once, we waited 10 minutes between sightings of the same species (assuming we had lost visual contact) before counting a second individual. The only exception was if we saw an individual land in a nest, then it was not included in the count because it was clearly a resident.

At a sub-sample of counts, two observers counted at the same counting station following the independent double-observer approach (Fletcher and Hutto 2006). Average detection probability was calculated for each observer ($\hat{p}_1$, $\hat{p}_2$) as well as both observers combined ($\hat{p}_t$). The same two observers conducted all the multiple observer counts.

We counted raptors at all paired stations 6 times (once in fall 2014, twice in spring and fall 2015, and once in spring 2016), except for one set of pairs each in the Bradshaw and Chiricahua Mountains; these paired stations were added after the fall of 2014 and we counted raptors at these paired stations 5 times each. Counts in both years were conducted between 12

September and 8 November in the fall, and between 12 February and 19 April in the spring. In the fall, we visited counting stations sequentially starting with the northern most station and moving south. The order was reversed during the spring, and matched movement direction for migrating raptors during each season. We assessed differences between high and low elevation counts, and between on- and off-river counts with Welch's two-tailed *t-tests* (Yuen 1974, Ramsey and Schafer 2002). We considered all counts to be independent, even when repeated counts (i.e., two) were conducted in the same fall or spring periods, because the "population" of raptors being counted at a station changed continuously during migration periods.

We assessed the relationship between counts of raptors and local weather conditions on individual counting days by relating counts to daily averages for temperature, wind speed, maximum wind speed, wind direction, and barometric pressure. We collected weather data from Weather Underground, a service of The Weather Company, and used data from the weather station located closest to each counting station. Weather stations were between 15 and 75 km of the counting stations. Measurements we used were average daily temperature in Kelvin (TEMP), average daily wind speed in meters per second (WS), average daily wind direction (WD), and average daily sea level pressure in inches (PRESSURE).

We used stepwise multiple linear regressions in R (R Core Team 2013, Mass and Leaps packages), to relate daily average counts to the four weather variables listed above. Wind direction was treated as a categorical variable and was divided into 16 categories (WD-N, WD-NNE, WD-NE, WD-ENE, WD-E, WD-ESE, WD-SE, WD-SSE, WD-S, WD-SSW, WD-SW, WD-WSW, WD-W, WD-WNW, WD-NW, and WD-NNW).

## 1.5 Results

Numbers of raptors observed during migration generally were higher in fall than spring at the mountain stations, but not along rivers (Tables 2, 3). When counts from both years were combined, weak evidence existed that mean numbers of raptors observed per hour were higher at high elevation stations ($\bar{x}$ = 3.09, $s$ = 2.64, $n$ = 22 counts) than at low elevation stations ($\bar{x}$ = 2.00, $s$ = 2.43) during fall ($t$ = 1.46, $P$ = 0.15) but not in spring (high sites, $\bar{x}$ = 1.5, $s$ = 2.07; low sites, $\bar{x}$ = 1.4, $s$ = 1.41, $n$ = 24 counts; $t$ = 0.24, $P$ = 0.81). We found no difference between mean numbers of raptors observed per hour at on- versus off-river stations in fall (fall on-river, $\bar{x}$ = 2.9, $s$ = 2.77; fall off-river, $\bar{x}$ = 1.5, $s$ = 1.28, $n$ = 6 counts; $t$ = 1.07, $P$ = 0.32), but counts at on-river stations were higher than off-river stations during spring (spring on-river, $\bar{x}$ = 1.4, $s$ = 0.87; spring off-river, $\bar{x}$ = 0.3, $s$ = 0.53, $n$ = 6 counts; $t$ = 2.85, $P$ = 0.03). Average height of observed raptors ranged from 25 to 135 m for spring and fall counts in high elevation, low elevation, on-river, and off–river counting stations (Figures 2, 3).

In spring, over half the variation in raptor counts at all counting stations was associated with weather factors on the day of the counts (Table 4). Raptor counts during this period were positively related to temperature, winds out of the NNW, and barometric pressure. During fall, only 20% of the variation in raptor counts were related to weather factors on the day of the counts. Raptor counts during this period were weakly, but positively associated with winds out of the WNW (Table 5).

We identified 15 species of diurnal raptors (including vultures) during the study, but most were seen less than 20 times (Table 6). The most common species observed were turkey vultures (*Cathartes aura*) and red-tailed hawks (*Buteo jamaicensis*) (Table 7). Merlins (*Falco columbarius*), golden eagles (*Aquila chrysaetos*), bald eagles (*Halieeatus leucocephalus*), peregrine falcons (*Falco peregrinus*), common black hawks (*Buteogallus anthracinus*), and Swainson's hawks (*Buteo swainsoni*) were seen five or fewer times (Table 6). The numbers of raptors we counted at the mountain and river stations in Arizona were in the lowest 10% of counts when compared to counting stations across the United States (Table 8) and in the lowest 15% when compared to counts in the Mississippi and Eastern Flyways (Table 9). However, the counts in central and southeastern Arizona were similar to most counting stations in the Pacific and Central Flyways (Table 10).

We used the multiple observer approach with two observers at 15 counts. Average detection probability for each observer was $\hat{p}_1 = 0.42$, and $\hat{p}_2 = 0.40$. Detection probability for both observers combined was $\hat{p}_t = 0.63$, $v\hat{a}r(p_t) = 0.03$.

## 1.6 Discussion

We found some evidence that the mountains in central and southeastern Arizona, and the rivers in southern Arizona, were used as migration corridors more than valley floors and off-river sites, respectively, but the patterns were not consistent in both fall and spring. Average counts of migrating raptors at counting stations in Arizona were low compared to average counts in the east, but comparable to average counts at about half of the counting stations in the Central and Pacific Flyways. For example, all but eight stations in the Central and Pacific flyways recorded, on average, between 1 and 17 raptors/hour. These rates of passage suggest that although there are some places where raptor migration in the west is concentrated (e.g., counting stations in the Goshutes Mountains and along the Gulf of Mexico), many places (including the mountains and rivers of southern Arizona) appear to facilitate relatively dispersed raptor migration. Raptor populations in both the western and eastern U.S. have recovered following a decline in the 1960's and 1970's, most likely caused by organochlorine compounds (DDT), and remain constant (Bednarz et al. 1990, Hoffman and Smith 2003). Although raptor migration appears to be more concentrated in the eastern U.S., there are still large numbers of raptors reported at western counting stations. The Goshute Mountain counting station averages 16,000 to 25,000 raptors each fall (Hoffman et al. 2002). Species composition between the western and eastern U.S. could influence raptor migration rates. Two complete migrant species are the broad-winged hawk and Swainson's hawk. Broad-winged hawks migrate almost exclusively in the eastern United States (Matray 1974), whereas Swainson's hawks migrate almost exclusively in the western United States (Fuller et al. 1998). However, we observed only one Swainson's hawk during our study, indicating they do not use the topographic features we studied when migrating. Swainson's hawks are an open-area, grassland species (Babcock 1995) and their migration routes reflect their specific habitat requirements (Kochert et al. 2011). The locations of counting stations and species observed could account for some of the variation seen between average counts in the western and eastern United States.

It should be noted that our counts almost certainly included some resident raptors. Many, but not all, raptors we counted were moving, but for those that were not moving, it was (with rare exceptions) impossible to differentiate between resident raptors and those that had stopped temporarily.

Although variation in raptors counts at the stations we established in Arizona was relatively low (both within and among counting stations), some of the variation in both spring and fall was related to daily weather conditions. In spring, raptor counts were positively associated with temperature, barometric pressure, and winds out of the NNW. In the fall, raptors counts were related to winds out of the WNW. The relationships among weather variables and raptor migration are complex (see Hall et al. 1992 for review), but higher rates of passage often are associated with warmer temperatures and rising barometric pressure (often after a cold front; Hall et al. 1992, Miller et al. 2011), and tailwinds. The direction of wind associated with our raptor counts in spring (NNW) was not a tailwind, but westerly winds and warm temperatures associated with high barometric pressure can create updrafts and thermals that are conducive to migration (Thomas et al. 2011).

Use of the independent double-observer approach highlighted the difficulty in detecting migrating raptors. Many raptors cannot be detected without the aid of binoculars, and remain visible for only a few seconds. View-sheds at the counting stations we established ranged from 180-270°. Consequently, even with constant scanning and binoculars, perfect detection was unlikely. The independent double-observer approach suggested that the probabilities of detecting raptors was consistent between the two observers ($\hat{p}_1$ = 0.42, $\hat{p}_2$ = 0.40); thus, an individual observer detected, on average, between 40 and 42% of raptors during the counting period. When two observers were present, approximately 63% of raptors were detected during the counting period ($\hat{p}_t$ = 0.63). Based on this value, as many as 4.6 raptors/hour went undetected by either observer. If the Arizona counts were adjusted with this correction factor, mean counts would range from 5.8 to 10.4 raptors/hour. We did not adjust the Arizona counts because the independent double-observer approach is rarely, if ever, applied at counting stations across the United States, making use of corrected values in comparisons inappropriate. However, even if corrected, estimates of raptors/hour at counting stations in Arizona remain low relative to counts at most counting stations in the eastern United States. Another counting station in the Aubrey Cliffs in Arizona recorded averages between 3.7 and 6.0 migrant raptors/hour over a three- year period between 2011 and 2013 (Kraft et al. 2012, Jacobson and McCarty 2013, and Jacobson et al. 2014). Our adjusted averages from the counting stations established in central and southeastern Arizona are comparable to those recorded at Aubrey Cliffs, as well as elsewhere in the western United States (Table 8).

## 1.7 Management Implications

The potential concentration of raptors along leading lines in the United States may present conflicts with the placement of wind turbines. Production of power from wind is quickly expanding in many countries (de Lucas et al. 2008), and wind turbines are often placed in the same locations that migrating raptors use because of updrafts and wind generation. Wind turbines add an obstacle for bird movement, and raptors are at a high risk for collision with rotating blades (Orloff and Flannery 1993, Morrison and Sinclair 1998, Smallwood 2007). In general, resident raptors tend to be at higher risk of collision with wind turbine blades than migrating raptors, but migrating, slope-soaring raptors tend to fly closer to the ridgeline than residents do, increasing their risk of collision (Katzner et al. 2012). The potential for mortality of raptors from wind turbines increases as the number of migrating raptors increases, and older turbines pose more of a risk to raptors than newer turbines (Orloff and Flannery 1993, Barclay et al. 2007). In the United States, wind turbines account for a small proportion of human-caused raptor mortality (Erickson et al. 2001, de Lucas et al. 2008) but assessing the long-term impacts of wind turbines on raptor mortality is difficult.

Wind turbines in the United States range in height from 24 to 94m (Barclay et al. 2007). Average height of raptors we observed at counting stations in Arizona ranged from 25 to 135 m. Although the mountains in central and southeastern Arizona, and the rivers in southern Arizona, do not have high concentrations of raptors during migration, the broad overlap between observed raptor height and height of wind turbines indicates that wind turbines still pose a risk. Red-tailed hawks and turkey vultures are at a high risk of collision because of their flight strategies (Hoover and Morrison 2005, Garvin et al. 2011). The dominate species observed at all counting stations in central and southeastern Arizona were red-tailed hawks and turkey vultures. And although we did not distinguish between resident and migrant flight heights, we propose that some mortality of both resident and migrant raptors can be expected if wind turbines are erected in these areas, especially because the dominate species seen at these sites are at an increased risk for collision.

## 1.7 List of Tables and Figures

Table 1. North latitudes and west longitudes (in meters) and elevations (m) of counting stations for migrating raptors established in Arizona, 2014-2016.

| Arizona Counting Stations | Latitude | Longitude | Elevation (m) |
|---|---|---|---|
| Bradshaw #1 High | 34.430629 | -112.389096 | 2209 |
| Bradshaw #1 Low | 34.451269 | -112.273933 | 1499 |
| Bradshaw #2 High | 34.483523 | -112.374145 | 1868 |
| Bradshaw #2 Low | 34.541633 | -112.399328 | 1709 |
| Chiricahua #1 High | 32.008459 | -109.312449 | 2097 |
| Chiricahua #1 Low | 32.009953 | -109.38429 | 1570 |
| Chiricahua #2 High | 31.910278 | -109.272684 | 2510 |
| Chiricahua #2 Low | 31.952124 | -109.309119 | 1824 |
| Dragoon High | 31.866333 | -109.951026 | 1865 |
| Dragoon Low | 31.876465 | -109.916526 | 1602 |
| Mule High | 31.471791 | -109.950712 | 2083 |
| Mule Low | 31.514817 | -110.046263 | 1387 |
| Pinal High | 33.284728 | -110.832677 | 2303 |
| Pinal Low | 33.342542 | -110.825569 | 1383 |
| Piñaleno High | 32.656388 | -109.860933 | 2770 |
| Piñaleno Low | 32.690435 | -109.760426 | 1261 |
| San Pedro (On River) | 31.725526 | -110.194439 | 1167 |
| San Pedro (Off River) | 31.739976 | -110.159427 | 1175 |

| | | | |
|---|---|---|---|
| Santa Cruz (On River) | 32.401331 | -111.146107 | 631 |
| Santa Cruz (Off River) | 32.401844 | -111.202692 | 640 |

Table 2. Number of raptors observed per hour during fall migrations in mountain ranges in central and southeastern Arizona, and rivers in southern Arizona, 2014-2015.

| | Year | | | |
|---|---|---|---|---|
| | 2014[a] | | 2015[b] | |
| Location | High/On[c] | Low/Off[d] | High/On | Low/Off |
| Bradshaw Mountains | 2.0 | 0.0 | 4.1 | 0.6 |
| Bradshaw Mountains 2 | | | 3.8 | 0.6 |
| Chiricahua Mountains | 8.8 | 3.0 | 6.3 | 6.4 |
| Chiricahua Mountains 2 | | | 5.6 | 5.6 |
| Dragoon Mountains | 1.0 | 3.2 | 2.7 | 3.4 |
| Mule Mountains | 1.2 | 0.4 | 2.6 | 1.0 |
| Pinal Mountains | 2.2 | 0.6 | 1.5 | 0.6 |
| Piñaleno Mountains | 2.0 | 1.4 | 1.5 | 1.1 |
| San Pedro River | 0.8 | 0.4 | 6.9 | 1.7 |
| Santa Cruz River | 1.0 | 3.0 | 2.7 | 1.1 |

[a]Number is based on one count.
[b]Numbers are averages of two counts.
[c]Number of raptors counted at high elevation sites in mountains, or on-river sites along rivers.
[d]Number of raptors counted at low elevation (i.e., valley floor) sites for mountains, or off-river sites along rivers.

Table 3. Number of raptors observed per hour during spring migrations in mountain ranges in central and southeastern Arizona, and rivers in southern Arizona, 2015-2016.

| | Year | | | |
|---|---|---|---|---|
| | 2015[a] | | 2016[b] | |
| Location | High/On[c] | Low/Off[d] | High/On | Low/Off |
| Bradshaw Mountains | 0.2 | 0.9 | 2.2 | 1.8 |
| Bradshaw Mountains 2 | 0.9 | 0.2 | 2.4 | 1.6 |
| Chiricahua Mountains | 5.4 | 3.6 | 2.6 | 4.4 |
| Chiricahua Mountains 2 | 2.0 | 1.8 | 0.2 | 1.4 |
| Dragoon Mountains | 0.7 | 1.9 | 0.6 | 0.2 |
| Mule Mountains | 1.9 | 0.1 | 1.0 | 0.6 |
| Pinal Mountains | 0.5 | 0.2 | 2.0 | 1.8 |
| Piñaleno Mountains | 0.7 | 0.9 | 0.8 | 1.0 |
| San Pedro River | 2.0 | 0.3 | 0.8 | 0.2 |
| Santa Cruz River | 1.6 | 0.3 | 0.4 | 1.4 |

[a]Numbers are averages of two counts.
[b]Numbers are based on one count.
[c]Number of raptors counted at high elevation sites in mountains, or on-river sites along rivers.
[d]Number of raptors counted at low elevation (i.e., valley floor) sites for mountains, or off-river sites along rivers.

Table 4. Stepwise multiple linear regression model relating daily counts of raptors during spring migration (2015 – 2016) and weather conditions during the counts (*n* = 44). Adjusted $R^2 = 0.57$; F-statistic = 6.59, 14 and 45 DF; *P*-value = 5.669e-07.

| Coefficient | Estimate | *P* |
|---|---|---|
| Intercept | -185.86 | 0.008 |
| TEMP | 0.20841 | 0.005 |
| NNW Wind | 3.83845 | 0.001 |
| PRESSURE | 4.24942 | 0.03 |

Table 5. Stepwise multiple linear regression model relating daily counts of raptors during fall migration (2015 – 2016) and weather conditions during the counts (*n* = 39). Adjusted $R^2 = 0.20$; F-statistic = 1.95, 14 and 40 DF; *P*-value = 0.05.

| Coefficient | Estimate | *P* |
|---|---|---|
| Intercept | -234.96 | 0.17 |
| WNW Wind | 5.220 | 0.05 |

Table 6. Species and number of raptors observed during spring and fall migrations in the mountain ranges and rivers in southeastern Arizona, 2015-2016.

| Fall | Spring | | | | |
|---|---|---|---|---|---|
| Species | Total | High/On[a] | Low/Off[b] | High/On | Low/Off |
| Turkey vulture (*Cathartes aura*) | 573 | 242 | 124 | 101 | 106 |
| Red-tailed hawk (*Buteo jamaicensis*) | 383 | 152 | 97 | 63 | 71 |
| Cooper's hawk (*Accipiter cooperii*) | 70 | 23 | 15 | 20 | 12 |
| American kestrel (*Falco sparverius*) | 50 | 20 | 17 | 8 | 5 |
| Unknown | 44 | 21 | 3 | 15 | 5 |
| Unknown Buteo | 23 | 13 | 1 | 7 | 2 |
| Northern goshawk (*Accipiter gentilis*) | 20 | 11 | 1 | 7 | 1 |
| Northern harrier (*Circus cyaneus*) | 10 | 3 | 1 | 4 | 2 |
| Unknown accipiter | 10 | 7 | 0 | 3 | 0 |
| Gray hawk (*Asturina nitida*) | 9 | 5 | 0 | 2 | 2 |
| Sharp-shinned hawk (*Accipiter striatus*) | 9 | 4 | 2 | 2 | 1 |
| Zone-tailed hawk (*Buteo albonotatus*) | 8 | 0 | 2 | 1 | 5 |
| Unknown falcon | 8 | 1 | 1 | 5 | 1 |
| Merlin (*Falco columbarius*) | 5 | 0 | 3 | 2 | 0 |
| Golden eagle | 4 | 3 | 1 | 0 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| (*Aquila chrysaetos*) | | | | | |
| Peregrine falcon (*Falco peregrinus*) | 4 | 3 | 0 | 1 | 0 |
| Bald eagle (*Haliaeetus leucocephalus*) | 1 | 0 | 0 | 1 | 0 |
| Common black hawk (*Buteogallus anthracinus*) | 1 | 1 | 0 | 0 | 0 |
| Swainson's hawk (*Buteo swainsoni*) | 1 | 0 | 1 | 0 | 0 |

[a]Number of raptors counted at high elevation sites in mountains, or on-river sites along rivers.
[b]Number of raptors counted at low elevation (i.e., valley floor) sites for mountains, or off-river sites along rivers.

Table 7. Total number of red-tailed hawks (*Buteo jamaicensis*) and turkey vultures (*Cathartes aura*) observed at counting stations during spring and fall migrations in the mountain ranges and rivers in southeastern Arizona, 2015-2016.

| Counting Station | Red-tailed hawk (*Buteo jamaicensis*) | Prop. of All Raptors Obs. | Turkey vulture (*Cathartes aura*) | Prop. of All Raptors Obs. |
|---|---|---|---|---|
| Bradshaw #1 Mountains | 21 | 0.24 | 26 | 0.29 |
| Bradshaw #2 Mountains | 23 | 0.29 | 39 | 0.49 |
| Chiricahua #1 Mountains | 88 | 0.24 | 230 | 0.64 |
| Chiricahua #2 Mountains | 84 | 0.46 | 76 | 0.42 |
| Dragoon Mountains | 58 | 0.46 | 32 | 0.26 |
| Mule Mountains | 18 | 0.29 | 21 | 0.33 |
| Pinal Mountains | 26 | 0.45 | 22 | 0.38 |
| Piñaleno Mountains | 23 | 0.32 | 18 | 0.25 |
| San Pedro River | 23 | 0.19 | 71 | 0.58 |
| Santa Cruz River | 21 | 0.25 | 40 | 0.47 |

Table 8. Average number of raptors observed per hour at counting stations across the United States in fall and spring combined, 2014 – 2016 (* denotes counting stations in central and southeastern Arizona).

| Counting Station | UTM Zone | State | Season | Avg. Raptors |
|---|---|---|---|---|
| Pinaleno Mtns | 12 | AZ | Fall/Spring | 1.2 |
| Pinal Mtns | 12 | AZ | Fall/Spring | 1.4 |
| Dragoon Mtns | 12 | AZ | Fall/Spring | 1.4 |
| Santa Cruz River | 12 | AZ | Fall/Spring | 1.7 |
| Mule Mtns | 12 | AZ | Fall/Spring | 1.9 |
| Dinosaur Ridge | 13 | CO | Spring | 2.0 |
| Bradshaw #1 Mtns | 12 | AZ | Fall/Spring | 2.1 |
| Bradshaw #2 Mtns | 12 | AZ | Fall/Spring | 2.4 |
| Pinnacle Rock | 19 | MA | Fall | 2.5 |
| Chiricahua #2 Mtns | 12 | AZ | Fall/Spring | 3.1 |
| San Pedro River | 12 | AZ | Fall/Spring | 3.2 |
| Marine Nature Area | 18 | NY | Fall | 3.3 |
| Chelan Ridge | 10 | WA | Fall | 3.4 |
| Tussey Mountain | 18 | PA | Spring | 4.7 |
| Kittatiny Mountain | 18 | NJ | Fall | 5.2 |
| Plum Island | 19 | MA | Spring | 5.8 |
| Chiricahua #1 Mtns | 12 | AZ | Fall/Spring | 5.8 |
| Fire Island | 18 | NY | Fall | 5.9 |
| Commissary Ridge | 12 | WY | Fall | 6.0 |
| Illinois Beach State Park | 16 | IL | Fall | 6.1 |
| Cumberland Gap | 17 | MD | Fall | 7.4 |
| Tubac HW | 12 | AZ | Spring | 7.6 |
| Pilgrim Heights | 19 | MA | Spring | 7.6 |
| Rose Tree Park | 18 | PA | Fall | 7.7 |

| | | | | |
|---|---|---|---|---|
| Turkey Point | 18 | MD | Fall | 8.0 |
| Greene Valley Forest Preserve | 16 | IL | Fall | 8.2 |
| MPG Ranch | 12 | MT | Fall | 8.2 |
| Franklin Moutain | 18 | NY | Fall | 8.8 |
| Bonney Butte | 10 | OR | Fall | 8.9 |
| Cadillac Mountain | 19 | ME | Fall | 8.9 |
| Allegheny Front | 17 | PA | Fall | 9.0 |
| Hitchcock Nature Center | 15 | IA | Fall | 9.3 |
| Bradbury Mountain SP | 19 | ME | Spring | 9.7 |
| Lenoir Wildlife Sanctuary | 18 | NY | Fall | 9.9 |
| Second Mountain | 18 | PA | Fall | 10.4 |
| Stone Mountain | 18 | PA | Fall | 10.4 |
| Jewel Basin | 12 | MT | Fall | 10.4 |
| Jacks Mountain | 18 | PA | Fall | 10.6 |
| Washington Monument SP | 18 | MD | Fall | 11.0 |
| Lipan Point | 12 | AZ | Fall | 11.1 |
| Manzano Mountains | 12 | NM | Fall | 11.3 |
| Ashland Nature Center | 18 | DE | Fall | 13.2 |
| Sunrise Mountain | 18 | NJ | Fall | 13.2 |
| Guana Preserve | 17 | FL | Fall | 13.4 |
| Lighthouse Point | 18 | CT | Fall | 13.5 |
| Hanging Rock Tower | 17 | WV | Fall | 13.6 |
| Mahogany Rock | 17 | NC | Fall | 13.7 |
| College Creek | 18 | VA | Fall | 14.0 |
| Rocky Face Mt. Rec Area | 17 | NC | Fall | 14.2 |
| Putney Mountain | 18 | VT | Fall | 14.3 |
| Carter Hill Observatory | 19 | NH | Fall | 14.4 |
| Bake Oven Knob | 18 | PA | Fall | 15.0 |
| Bethany HW | 15 | MN | Fall | 15.2 |

| | | | | |
|---|---|---|---|---|
| Militia Hill | 18 | PA | Fall | 15.2 |
| Chimney Rock | 18 | NJ | Fall | 16.0 |
| Fort Sheridan | 16 | IL | Fall | 16.1 |
| Hook Mountain | 18 | NY | Fall | 16.2 |
| Hawk Mountain Sanctuary | 18 | PA | Fall | 16.3 |
| Montclair HW | 18 | NJ | Fall | 16.3 |
| Tuscacora Summit | 18 | PA | Fall | 16.7 |
| Boothe Memorial Park | 18 | CT | Fall | 16.7 |
| Harpswell Peninsula | 19 | ME | Fall | 17.2 |
| Little Round Top | 19 | NH | Fall | 17.2 |
| Yaki Point | 12 | AZ | Fall | 17.3 |
| Cape Henlopen | 18 | DE | Fall | 17.4 |
| Council Cap | 18 | PA | Fall | 17.9 |
| Quaker Ridge | 18 | CT | Fall | 18.1 |
| Brockway Mountain | 16 | MI | Spring | 18.1 |
| Wildcat Ridge | 18 | NJ | Fall | 18.4 |
| Harvey's Knob | 17 | VA | Fall | 18.9 |
| Racoon Ridge | 18 | NJ | Fall | 19.9 |
| S.C. Coastal Hwy | 17 | SC | Fall | 20.0 |
| State Line HW | 18 | NJ | Fall | 20.0 |
| Blueberry Hill | 18 | MA | Fall | 21.3 |
| Little Gap | 18 | PA | Fall | 21.5 |
| Whitefish Point | 16 | MI | Spring | 22.1 |
| Caesar's Head | 17 | SC | Fall | 22.2 |
| Waggoner's Gap | 18 | PA | Fall | 23.0 |
| Port Huron | 17 | MI | Spring | 23.5 |
| Fort Smallwood | 18 | MD | Fall | 23.5 |
| Summitville | 18 | NY | Fall | 23.7 |
| Mount Peter | 18 | NY | Fall | 24.3 |

| | | | | |
|---|---|---|---|---|
| Eagle Valley | 15 | WI | Fall | 25.7 |
| Belmont Valley | 17 | VA | Fall | 26.0 |
| Barre Falls | 18 | MA | Fall | 27.1 |
| Rockfish Gap | 17 | VA | Fall | 30.2 |
| Pack Monadock | 19 | NH | Fall | 30.8 |
| Mendota Fire Tower | 17 | VA | Fall | 31.3 |
| Scott's Mountain | 18 | NJ | Fall | 31.5 |
| Kiptopeke HW | 18 | VA | Fall | 34.6 |
| Middle School | 18 | CT | Fall | 35.5 |
| Cape May | 18 | NJ | Fall | 37.5 |
| Snicker's Gap | 18 | VA | Fall | 39.3 |
| Shatterack Mountain | 18 | MA | Fall | 39.4 |
| Cromwell Valley Park | 18 | MD | Fall | 40.0 |
| Pilot Mountain SP | 17 | NC | Fall | 44.3 |
| Johnnycake Mountain | 18 | CT | Fall | 45.4 |
| Wachusett Mountain | 19 | MA | Fall | 49.0 |
| Grandfather Mountain | 17 | NC | Fall | 49.1 |
| Botsford Hill | 18 | CT | Fall | 53.0 |
| Clarry Hill | 19 | ME | Fall | 58.8 |
| Hamburg HW | 17 | NY | Fall | 59.3 |
| West Skyline | 15 | MN | Fall | 61.8 |
| Florida Keys | 17 | FL | Fall | 68.1 |
| Borrego Valley | 11 | CA | Spring | 68.2 |
| Derby Hill | 18 | NY | Spring | 78.4 |
| Goshute Mountains | 11 | NV | Fall | 80.6 |
| Chesnut Hill | 18 | CT | Fall | 81.6 |
| Mill Creek Road | 16 | AL | Fall | 82.1 |
| Mackinac Straits | 16 | MI | Spring | 83.1 |
| Hawk Ridge | 15 | MN | Fall | 87.1 |

| | | | | |
|---|---|---|---|---|
| Smith Point | 15 | TX | Fall | 92.0 |
| Good Hill | 18 | CT | Fall | 93.1 |
| Presque Island | 17 | PA | Spring | 95.4 |
| Ripley Hawkwatch | 17 | NY | Spring | 114.1 |
| Santa Ana Refuge | 14 | TX | Spring | 114.8 |
| Port Crescent Hawkwatch | 17 | MI | Spring | 139.2 |
| Booth Hill | 18 | CT | Fall | 149.6 |
| Broadwing | 18 | PA | Fall | 152.1 |
| Detroit River | 17 | MI | Fall | 379.0 |
| Bentsen Rio Grande | 14 | TX | Fall | 557.7 |
| Corpus Christi | 14 | TX | Fall | 696.6 |

Table 9. Average number of raptors observed per hour at counting stations in the Mississippi and Atlantic Flyways in comparison to those established in central and southeastern Arizona, 2014-2016. (*denotes counting stations in central and southeastern Arizona).

| Counting Station | UTM Zone | State | Season | Avg. Raptors |
|---|---|---|---|---|
| Pinaleno Mtns* | 12 | AZ | Fall/Spring | 1.2 |
| Pinal Mtns* | 12 | AZ | Fall/Spring | 1.4 |
| Dragoon Mtns* | 12 | AZ | Fall/Spring | 1.4 |
| Santa Cruz River* | 12 | AZ | Fall/Spring | 1.7 |
| Mule Mtns* | 12 | AZ | Fall/Spring | 1.9 |
| Bradshaw #1 Mtns* | 12 | AZ | Fall/Spring | 2.1 |
| Bradshaw #2 Mtns* | 12 | AZ | Fall/Spring | 2.4 |
| Pinnacle Rock | 19 | MA | Fall | 2.5 |
| Chiricahua #2 Mtns* | 12 | AZ | Fall/Spring | 3.1 |
| San Pedro River* | 12 | AZ | Fall/Spring | 3.2 |
| Marine Nature Area | 18 | NY | Fall | 3.3 |
| Tussey Mountain | 18 | PA | Spring | 4.7 |
| Kittatiny Mountain | 18 | NJ | Fall | 5.2 |
| Plum Island | 19 | MA | Spring | 5.8 |
| Chiricahua #1 Mtns* | 12 | AZ | Fall/Spring | 5.8 |
| Fire Island | 18 | NY | Fall | 5.9 |
| Illinois Beach State Park | 16 | IL | Fall | 6.1 |
| Cumberland Gap | 17 | MD | Fall | 7.4 |
| Pilgrim Heights | 19 | MA | Spring | 7.6 |
| Rose Tree Park | 18 | PA | Fall | 7.7 |
| Turkey Point | 18 | MD | Fall | 8.0 |
| Greene Valley Forest Preserve | 16 | IL | Fall | 8.2 |
| Franklin Mountain | 18 | NY | Fall | 8.8 |
| Cadillac Mountain | 19 | ME | Fall | 8.9 |
| Allegheny Front | 17 | PA | Fall | 9.0 |
| Bradbury Mountain SP | 19 | ME | Spring | 9.7 |
| Lenoir Wildlife Sanctuary | 18 | NY | Fall | 9.9 |

| | | | | |
|---|---|---|---|---|
| Second Mountain | 18 | PA | Fall | 10.4 |
| Stone Mountain | 18 | PA | Fall | 10.4 |
| Jacks Mountain | 18 | PA | Fall | 10.6 |
| Washington Monument SP | 18 | MD | Fall | 11.0 |
| Ashland Nature Center | 18 | DE | Fall | 13.2 |
| Sunrise Mountain | 18 | NJ | Fall | 13.2 |
| Guana Preserve | 17 | FL | Fall | 13.4 |
| Lighthouse Point | 18 | CT | Fall | 13.5 |
| Hanging Rock Tower | 17 | WV | Fall | 13.6 |
| Mahogany Rock | 17 | NC | Fall | 13.7 |
| College Creek | 18 | VA | Fall | 14.0 |
| Rocky Face Mt. Rec Area | 17 | NC | Fall | 14.2 |
| Putney Mountain | 18 | VT | Fall | 14.3 |
| Carter Hill Observatory | 19 | NH | Fall | 14.4 |
| Bake Oven Knob | 18 | PA | Fall | 15.0 |
| Bethany HW | 15 | MN | Fall | 15.2 |
| Militia Hill | 18 | PA | Fall | 15.2 |
| Chimney Rock | 18 | NJ | Fall | 16.0 |
| Fort Sheridan | 16 | IL | Fall | 16.1 |
| Hook Mountain | 18 | NY | Fall | 16.2 |
| Hawk Mountain Sanctuary | 18 | PA | Fall | 16.3 |
| Montclair HW | 18 | NJ | Fall | 16.3 |
| Tuscacora Summit | 18 | PA | Fall | 16.7 |
| Boothe Memorial Park | 18 | CT | Fall | 16.7 |
| Harpswell Peninsula | 19 | ME | Fall | 17.2 |
| Little Round Top | 19 | NH | Fall | 17.2 |
| Cape Henlopen | 18 | DE | Fall | 17.4 |
| Council Cap | 18 | PA | Fall | 17.9 |
| Quaker Ridge | 18 | CT | Fall | 18.1 |
| Brockway Mountain | 16 | MI | Spring | 18.1 |
| Wildcat Ridge | 18 | NJ | Fall | 18.4 |

| | | | | |
|---|---|---|---|---|
| Harvey's Knob | 17 | VA | Fall | 18.9 |
| Raccoon Ridge | 18 | NJ | Fall | 19.9 |
| S.C. Coastal Hwy | 17 | SC | Fall | 20.0 |
| State Line HW | 18 | NJ | Fall | 20.0 |
| Blueberry Hill | 18 | MA | Fall | 21.3 |
| Little Gap | 18 | PA | Fall | 21.5 |
| Whitefish Point | 16 | MI | Spring | 22.1 |
| Caesar's Head | 17 | SC | Fall | 22.2 |
| Waggoner's Gap | 18 | PA | Fall | 23.0 |
| Port Huron | 17 | MI | Spring | 23.5 |
| Fort Smallwood | 18 | MD | Fall | 23.5 |
| Summitville | 18 | NY | Fall | 23.7 |
| Mount Peter | 18 | NY | Fall | 24.3 |
| Eagle Valley | 15 | WI | Fall | 25.7 |
| Belmont Valley | 17 | VA | Fall | 26.0 |
| Barre Falls | 18 | MA | Fall | 27.1 |
| Rockfish Gap | 17 | VA | Fall | 30.2 |
| Pack Monadock | 19 | NH | Fall | 30.8 |
| Mendota Fire Tower | 17 | VA | Fall | 31.3 |
| Scott's Mountain | 18 | NJ | Fall | 31.5 |
| Kiptopeke HW | 18 | VA | Fall | 34.6 |
| Middle School | 18 | CT | Fall | 35.5 |
| Cape May | 18 | NJ | Fall | 37.5 |
| Snicker's Gap | 18 | VA | Fall | 39.3 |
| Shatterack Mountain | 18 | MA | Fall | 39.4 |
| Cromwell Valley Park | 18 | MD | Fall | 40.0 |
| Pilot Mountain SP | 17 | NC | Fall | 44.3 |
| Johnnycake Mountain | 18 | CT | Fall | 45.4 |
| Wachusett Mountain | 19 | MA | Fall | 49.0 |
| Grandfather Mountain | 17 | NC | Fall | 49.1 |
| Botsford Hill | 18 | CT | Fall | 53.0 |

| | | | | |
|---|---|---|---|---|
| Clarry Hill | 19 | ME | Fall | 58.8 |
| Hamburg HW | 17 | NY | Fall | 59.3 |
| West Skyline | 15 | MN | Fall | 61.8 |
| Florida Keys | 17 | FL | Fall | 68.1 |
| Derby Hill | 18 | NY | Spring | 78.4 |
| Chesnut Hill | 18 | CT | Fall | 81.6 |
| Mill Creek Road | 16 | AL | Fall | 82.1 |
| Mackinac Straits | 16 | MI | Spring | 83.1 |
| Hawk Ridge | 15 | MN | Fall | 87.1 |
| Good Hill | 18 | CT | Fall | 93.1 |
| Presque Island | 17 | PA | Spring | 95.4 |
| Ripley Hawkwatch | 17 | NY | Spring | 114.1 |
| Port Crescent Hawkwatch | 17 | MI | Spring | 139.2 |
| Booth Hill | 18 | CT | Fall | 149.6 |
| Broadwing | 18 | PA | Fall | 152.1 |
| Detroit River | 17 | MI | Fall | 379.0 |

Table 10. Average number of raptors observed per hour at counting stations in the Central and Pacific Flyways, 2014 – 2016 (* denotes counting stations in central and southeastern Arizona with both fall and spring averages).

| Counting Station | UTM Zone | State | Season | Avg. Raptors |
|---|---|---|---|---|
| Pinaleno Mtns* | 12 | AZ | Fall/Spring | 1.2 |
| Pinal Mtns* | 12 | AZ | Fall/Spring | 1.4 |
| Dragoon Mtns* | 12 | AZ | Fall/Spring | 1.4 |
| Santa Cruz River* | 12 | AZ | Fall/Spring | 1.7 |
| Mule Mtns* | 12 | AZ | Fall/Spring | 1.9 |
| Dinosaur Ridge | 13 | CO | Spring | 2.0 |
| Bradshaw #1 Mtns* | 12 | AZ | Fall/Spring | 2.1 |
| Bradshaw #2 Mtns* | 12 | AZ | Fall/Spring | 2.4 |
| Chiricahua #2 Mtns* | 12 | AZ | Fall/Spring | 3.1 |
| San Pedro River* | 12 | AZ | Fall/Spring | 3.2 |
| Chelan Ridge | 10 | WA | Fall | 3.4 |
| Chiricahua #1 Mtns* | 12 | AZ | Fall/Spring | 5.8 |
| Commissary Ridge | 12 | WY | Fall | 6.0 |
| Tubac HW | 12 | AZ | Spring | 7.6 |
| MPG Ranch | 12 | MT | Fall | 8.2 |
| Bonney Butte | 10 | OR | Fall | 8.9 |
| Hitchcock Nature Center | 15 | IA | Fall | 9.3 |
| Jewel Basin | 12 | MT | Fall | 10.4 |
| Lipan Point | 12 | AZ | Fall | 11.1 |
| Manzano Mountains | 12 | NM | Fall | 11.3 |
| Yaki Point | 12 | AZ | Fall | 17.3 |
| Borrego Valley | 11 | CA | Spring | 68.2 |
| Goshute Mountains | 11 | NV | Fall | 80.6 |
| Smith Point | 15 | TX | Fall | 92.0 |
| Santa Ana Refuge | 14 | TX | Spring | 114.8 |

| | | | | |
|---|---|---|---|---|
| Bentsen Rio Grande | 14 | TX | Fall | 557.7 |
| Corpus Christi | 14 | TX | Fall | 696.6 |

Figure 1. Locations of the mountain ranges and rivers in which counting stations for migrating raptors were established in 2014 and 2015, Arizona (two stations established in the Bradshaw and Chiricahua Mountains are represented by one black dot in each range).

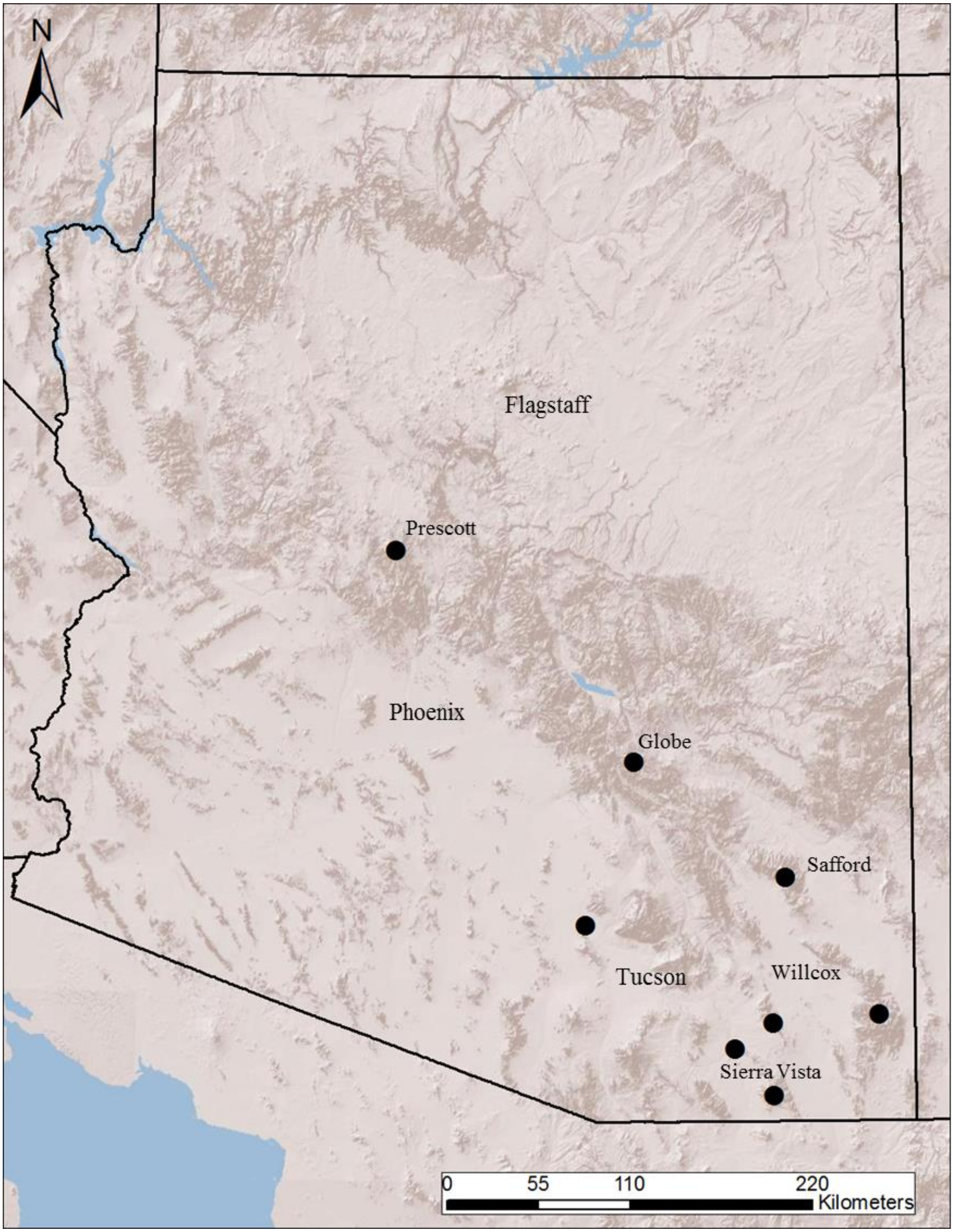


Figure 2. Mean height of raptors observed in fall (2014-2015) at high elevation, low elevation, on-river, and off-river counting stations in Arizona. Black dots represent mean flight height and error bars represent one standard deviation above and below the mean.

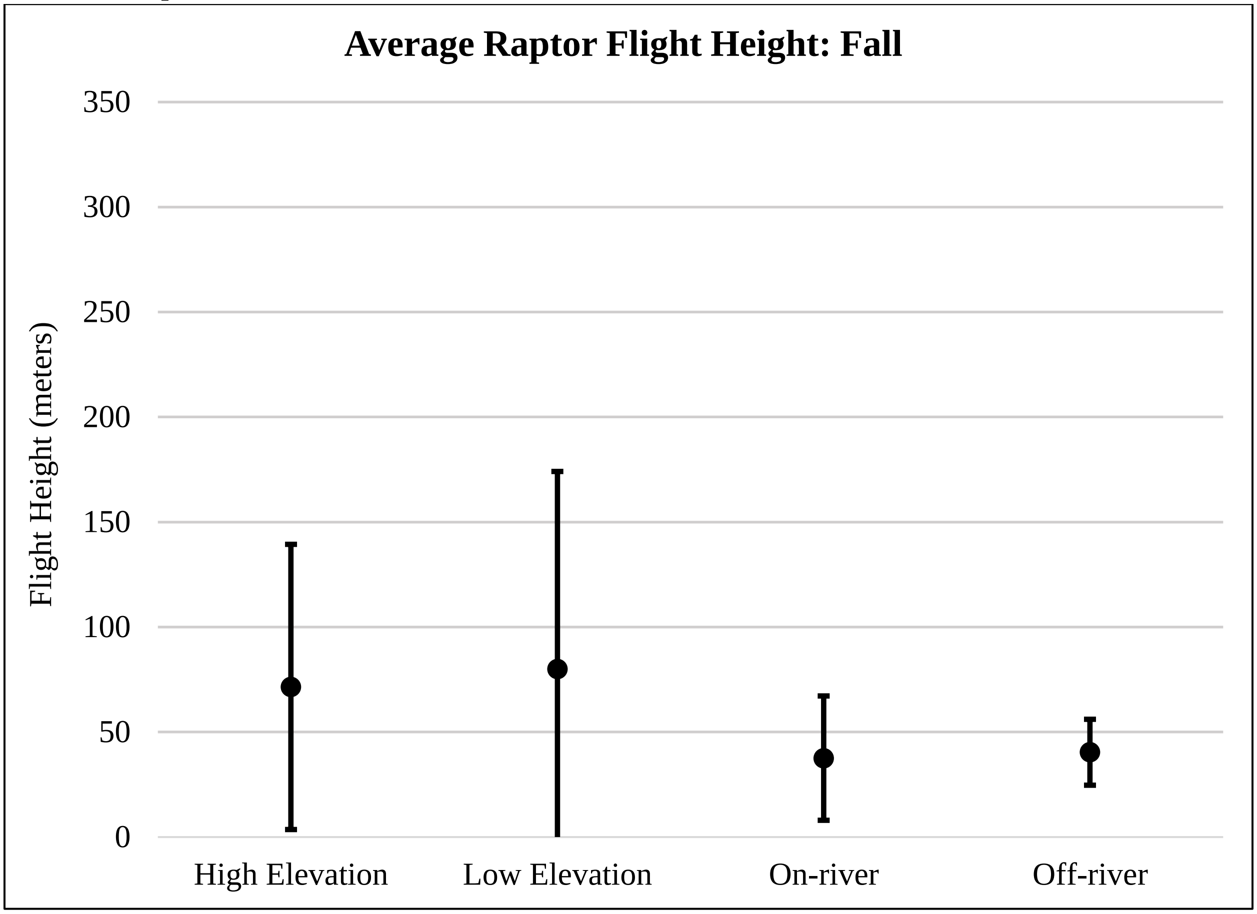
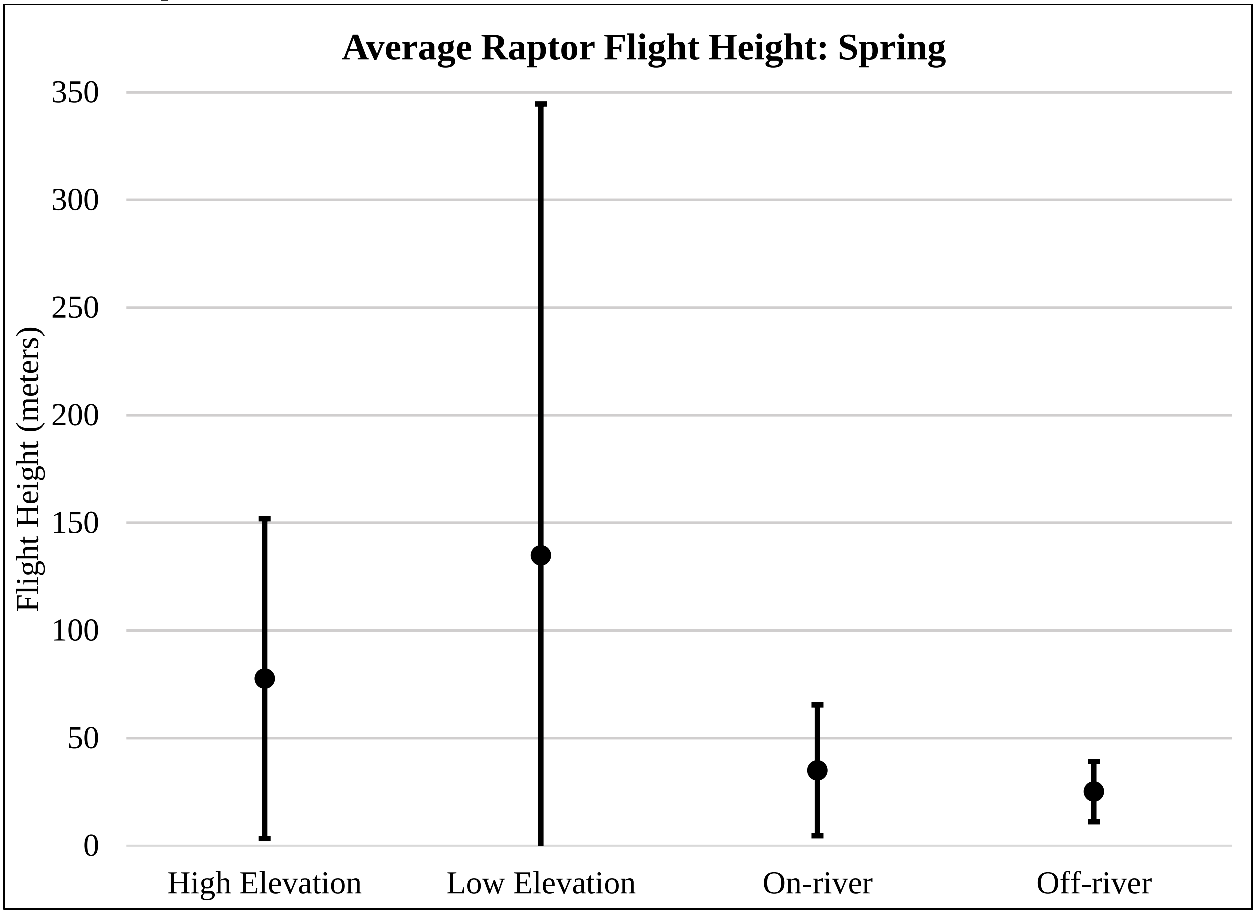


Figure 3. Mean height of raptors observed in spring (2015-2016) at high elevation, low elevation, on-river, and off-river counting stations in Arizona. Black dots represent mean flight height and error bars represent one standard deviation above and below the mean.



1.8 Literature Cited


Allen, P.E., L.J. Goodrich, and K.L. Bildstein. 1996. Within- and among- year effects of cold fronts on migrating raptors at Hawk Mountain, Pennsylvania, 1934-1991. *The Auk*113(2): 329-338.

Babcock, K.W. 1995. Home range and habitat use of breeding Swainson's hawks in the Sacramento Valley of California. *Journal of Raptor Research* 29(3): 193-197.

Bahre, C.J. and M.L. Shelton. 1993. Historic vegetation change, mesquite increases, and climate in southeastern Arizona. *Journal of Biogeography* 20: 489-504.

Barclay, R.M.R, E.F. Baerwald, and J.C. Gruver. 2007. Variation in bat and bird fatalities at wind energy facilities: assessing the effects of rotor size and tower height. *Canadian Journal of Zoology* 85: 381-387.

Bednarz, J.C., D. Klem Jr., L.J. Goodrich, and S.E. Senner. 1990. Migration counts of raptors at Hawk Mountain, Pennsylvania, as indicators of population trends, 1934-1986. *The Auk* 107: 96-109.

de Lucas, M., G.F.E. Janss, D.P. Whitfield, and M. Ferrer. 2008. Collision fatality of raptors in wind farms does not depend on raptor abundance. *Journal of Applied Ecology* 45: 1695-1703.

Erickson, W.P., G.D. Johnson, M.D. Strickland, D.P. Young Jr., K.J. Sernka, and R.E. Good. 2001. Avian collisions with wind turbines: a summary of existing studies and comparisons to other sources of avian mortality in the United States. National Wind Coordinating Committee Resource Document.

Fletcher, R.J. and R.L. Hutto. 2006. Estimating detection probabilities of river birds using double surveys. *The Auk* 123: 695-707.

Fuller, M.R., W.S. Seegar, and L.S. Schueck. 1998. Routes and travel rates of migrating peregrine falcons (*Falco peregrinus*) and Swainson's hawks (*Buteo swainsoni*) in the western hemisphere. *Journal of Avian Biology* 29(4): 433-440.

Garvin, J.C., C.S. Jennelle, D. Drake, and S.M. Grodsky. 2011. Response of raptors to a windfarm. *Journal of Applied Ecology* 48(1): 199-209.

Hall, L.S., A.M. Fish, and M.L. Morrison. 1992. The influence of weather on hawk movements in coastal Northern California. *The Wilson Bulletin* 104(3): 447-461.

Hirt, P. 1989. The transformation of a landscape: culture and ecology in southeastern Arizona. *Environmental Review* 13: 167-189.

"Historical Weather." *Weather Underground*. N.p., n.d. Web. 29 Mar. 2017. https://www.wunderground.com/history/.

Hoffman, S.W. and J.P. Smith. 2003. Population trends of migratory raptors in the western North America. *The Condor* 105(3): 397-413.

Hoffman, S.W., J.P. Smith, and T. Meehan. 2002. Breeding grounds, winter ranges, and migratory routes of raptors in the mountain west. *Journal of Raptor Research* 36: 97 110.

Hoover, S.L. and M.L. Morrison. 2005. Behavior of red-tailed hawks in a wind turbine development. *The Journal of Wildlife Management* 69(1): 150-159.

Jacobson, K.V. and K.M. McCarty. 2013. Raptor migration counts Aubrey Cliffs, Arizona: Fall 2012 Summary Report. Rep. no. 274.

Jacobson, K.V., K.M. McCarty, and T. Coleman. 2014. Raptor migration counts Aubrey Cliffs Arizona: Fall 2013 Summary Report. Rep. no. 282.

Katzner, T.E., d. Brandes, T. Miller, M. Lanzone, C. Maisonueve, J.A. Tremblay, R. Mulhivill and G.T. Merovich Jr. 2012. Topography drives migratory flight altitude of golden eagles: implications for on-shore wind development energy. *Journal of Applied Ecology* 49: 1178-186.

Klaassen R.H.G, M. Hake, R. Strandberg, and T. Alerstam. 2010. Geographical and temporal flexibility in the response to crosswinds by migrating raptors. *Proceedings of the Royal Society Biological Sciences* DOI: 10.1098/rspb.2010.2106.

Koch, G. 2006. Using a Doppler light detection and ranging (lidar) system to characterize an atmospheric thermal providing lift for soaring raptors. *Journal of Field Ornithology* 77: 315-318.

Kochert, M.N., M.R. Fuller, L.S. Schueck, L. Bond, M.J. Bechard, B. Woodbridge, G.L. Holroyd, M.S. Martell, and U. Banasch. 2011. Migration patterns, use of stopover areas, and austral summer movements of Swainson's hawks. *The Condor* 113(1): 89-106.

Kraft, John P., Kyle M. McCarty, and Kenneth V. Jacobson. 2012. Raptor migration counts of the Aubrey Cliffs, Arizona: Fall 2011 Summary Report. Rep. no. 269.

Matray, P. 1974. Broad-winged hawk nesting and ecology. *The Auk* 91(2): 307-324.

Miller, R.A., J.D. Carlisle, and G.S. Kaltnecker. 2011. Effects of regional cold fronts and localized weather phenomena on autumn migration of raptors and landbirds in southwest Idaho. *The Condor* 113(2): 274-283.

Morehouse, B.J., R.H. Carter, and T.W. Sprouse. 2000. The implications of sustained drought for transboundary water management in Nogales, Arizona and Nogales, Sonora. *Natural Resources Journal* 40(4): 783-817.

Morrison, M.L., and K. Sinclair. 1998. Avian risk and fatality protocol. National Renewable Energy Laboratory.

Mueller, H.C., and D.D. Berger. 1967. Wind drift, leading lines, and diurnal migration. *Wilson Bulletin* 79:50-63.

Niles, L.J., J. Burger, and K.E. Clark. 1996. The influence of weather, geography, and habitat on migrating raptors on Cape May Peninsula. *The Condor* 98 (2): 382-394.

Orloff, S. and A. Flannery. 1993. Wind turbine effects on avian activity, habitat use and mortality in Altamont Pass and Solano County Wind Resource Areas, 1989–91. California. Energy Commission.

R Core Team. 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/.

Ramsey, F. L., and D.W. Schafer. 2002. The statistical sleuth: a course in methods of data analysis. 2nd ed. Boston: Brooks/Cole, Cengage Learning. Print.

Seeland, H.M. and G.J. Niemi. 2012. Determination of raptor migratory patterns over a large landscape. *Journal of Raptor Research* 46 (3): 283-295.

Smallwood, K.S. 2007. Estimating wind turbine-caused bird mortality. *The Journal of Wildlife Management* 71(8): 2781-2791.

Stromberg, J.C., R. Tiller, and B. Richter. 1996. Effects of groundwater decline on riparian vegetation of semiarid regions: The San Pedro River, Arizona. *Ecological Application* 6(1): 113-131.

Stout, W.E., V.L. Greene, and S. Postupalsky. 2009. Migration routes, reproduction, and lifespan of a translocated osprey. *The Wilson Journal of Ornithology* 121(1): 203-206.

Thomas, P.J., A.K. LaBrosse, A.C. Pomeroy, and K.A. Otter. 2011. Effects of weather on avian migration at proposed ridgeline wind energy sites. *Journal of Wildlife Management* 75: 805-815.

Wiltschko, W. and R. Wiltschko. 2005. Magnetic orientation and magnetoreception in birds and other animals. *Journal of Comparative Physiology* 191(8): 675-693.

Wiltschko, W., P. Weindler, and R. Wiltschko. 1998. Interaction of magnetic and celestial cues in the migratory orientation of passerines. *Journal of Avian Biology* 29(4): 606-617.

Yuen, K.K. 1974. The two-sample trimmed t for unequal population variances. *Biometrika* 61(1): 165-170.

**Appendix II. Assessment of raptor migration corridors in the United States**

2.1 Abstract

Raptors use “leading lines” or topographic features, such as mountain ranges, rivers, and coastlines that help guide them during their migration, and sometimes are redirected by diversion lines, or barriers that they are hesitant to cross (e.g., large bodies of water). Ecological factors also play a role in migration routes for raptors, and raptors may select stopover sites that are most similar to their wintering and breeding grounds. There are well-established migration routes for raptors in North America, and during spring and fall, efforts are made to count migrating raptors at a variety of sites in North America. Counts range from 2.0 to 810.3 raptors/hour and high counts at some stations can be explained by obvious leading lines or diversion barriers, but less is known about the characteristics of sites that do not have obvious leading lines or diversion barriers. We investigated the physical and ecological features that potentially influence raptor migration in North America by collecting count data from counting stations across the United States and relating it to the physical and ecological features around the counting stations. Measures we made were intended to depict the degree of continuity or connectedness of land cover, elevation, and rivers around counting stations, and to assess the distance a counting station was from the nearest major diversion barrier. A stepwise linear regression model for the spring accounted for substantial variation in the data (adjusted $R^2$=0.73) and indicated that counts were negatively related to the distance from a diversion barrier and positively related to continuity of land cover type and elevation. A stepwise linear regression model for fall accounted for less variation in the data (adjusted $R^2$=0.13) and indicated counts were negatively related to the distance from a diversion barrier and positively related to continuous elevation and length of rivers around the counting station. We compared models for counting stations across the United States to models for counting stations in the Pacific and Central flyways. Both models produced

similar results and suggested they are appropriate for predicting raptor migration rates across the United States.

## 2.2 Introduction

Of the 36 diurnal raptor species in North America, 31 (~86%) are either complete or partial migrants and move from breeding to wintering areas during the fall and spring (Bildstein 2006, Goodrich and Smith 2008). Raptors use visual cues when migrating (Klaassen et al. 2010), unlike other avian species that use magnetic fields and celestial bodies (Wiltschko et al. 1998, Wiltschko and Wiltschko 2005). While migrating, raptors are known to use “leading lines” or topographic features, such as mountain ranges, rivers, and coastlines that help guide them during their movements (Mueller and Berger 1967), and sometimes are redirected by diversion barriers. Diversion barriers are large bodies of water raptors are hesitant to cross (Baird and Nisbet 1960, Farmer et al. 2007). Ecological factors also play a role in migration routes for raptors (Goodrich and Smith 2008). For example, migration routes sometimes include stopover sites, which provide food and cover (Moore and Aborn 2000), and raptors often select stopover sites that are similar to their breeding or wintering grounds (Niles et al. 1996).

There are many well-established migration routes for raptors in North America. Most are consistent with the flyways of North American migratory birds: Atlantic Flyway, Mississippi Flyway, Central Flyway, and Pacific Flyway (Hoffman et al. 2002). During the fall and spring, efforts are made to count migrating raptors at a variety of sites in North America. Count stations are often located in places where large numbers of raptors can be seen, but counts per hour vary widely across sites (e.g., from 2.0 to 810.3/hour). Raptor populations remain constant in both the western and eastern United States (Bednarz et al. 1990, Hoffman and Smith 2003) and large number of raptors are observed at counting stations in both the west and east each year (Hoffman et al. 2002, Goodrich and Smith 2008). The high counts at some stations can be explained by obvious leading lines or diversion barriers (e.g., mountain ranges, rivers, coastlines, and lakes), and the characteristics of several individual count stations have been described (Niles et al. 1996, Littlefield and Johnson 2013). However, little is known about the characteristics of count sites that do not have obvious leading lines or diversion barriers, and no meta-analysis or comprehensive description of all count stations has been conducted.

We investigated the physical and ecological features that potentially influence raptor migration in North America by characterizing count stations and relating their features to the number of raptors counted annually during migration.

## 2.3 Study Sites

Counting stations ranged from the Pacific Coast to the Atlantic Coast, and as far north as Canada and as far south as the Florida Keys. Elevation, land cover type, and percentage of open water varied greatly among counting stations. Counting stations in the west were characterized mostly by evergreen forest, mixed forest, grassland, and shrub/scrub, with sharp changes in elevation and little open water. Counting stations in the east were also mostly characterized by evergreen, mixed, and deciduous forest, but less varied in elevation than in the west. Counting stations in the east were also near more rivers and open water than the west. Counting stations located near the Atlantic Ocean or Great Lakes were characterized by woody wetlands and emergent herbaceous wetlands, continuously low elevation, and large proportion of open water.

## 2.4 Methods

Our primary objective was to characterize the physical and weather conditions of counting stations where migrating raptors are most common. We compared numbers of raptors counted and landscape features at 112 counting stations from across the United States (Table 1, 2) to the counting stations we established in central and southeastern Arizona (Table 1, 2) (McHugh 2017). We collected count data from counting stations across the United States that reported counts in fall 2014, spring 2015, fall 2015, and spring 2016 (i.e., the same periods that data were collected in southern Arizona) from the Hawk Migration Association of North America (HMANA, hawkcount.org). We calculated counts per hour to standardize for differences in effort across stations, and averaged counts across all years for each season when necessary (i.e., fall and spring).

Locations of all counting stations were entered into ArcGIS (ESRI 2011) and projected into the correct coordinate system, depending on UTM zone. We used the buffer tool in ArcGIS to create a buffer area, 200 km in diameter, centered on each counting station. Average daily raptor migration distances range anywhere from 100 to 350 km, and 200 km falls well within this range (Chavez-Ramirez et al. 1994, Mandel et al. 2008). All measurements describing landscape features around counting stations were made within this buffer area. Measures we made were intended to depict the degree of continuity or connectedness of land cover, elevation, and rivers. We used the National Land Cover Database (NLCD) 2011 (30 by 30 m resolution) (Homer et al. 2015) for analyses of land cover, the U.S. Geological Survey digital elevation maps (DEM) (30 by 30 m resolution) for measures of elevation continuity, and "Made with Natural Earth" (10 by 10 m resolution, accessed March 2017) for measures of river length. NLCD rasters were reclassified into nine land cover types: Open Water, Developed, Barren land, Forest, Shrub/Scrub, Grassland/Herbaceous, Cropland, Woody Wetlands, and Emergent Herbaceous Wetlands. DEM rasters were reclassified into two elevation classes: one encompassing from 152.4 m (500 ft) below the elevation of the counting station and above, and the second from 152.4 m (500 ft) below the count station and below. We used FRAGSTATS (McGarigal et al. 2012) to estimate measures of connectivity for land cover and elevation (Table 3). Measure we made were the proportion of the buffer area comprised of the predominant land cover type within a 500 m radius of the counting station (PLAND), the average distance an organism could move before reaching the patch boundary, starting from a random point, and moving in a random direction within a patch of the predominant land cover type (GYRATE_ NLCD) or the elevation class above the counting station (GYRATE_DEM), the proportion of like patch types surrounding a given patch of the predominant land cover type averaged across all patches (Aggregation Index or AI), and the probability that two randomly chosen pixels within the buffer area were not in the same patch of elevation class (i.e., the class above the elevation of the counting station) (DIVISION_DEM). We used ArcGIS for measures related to distance (Table 3). Measure made were distance to nearest major diversion line (BARRIER). We considered the Pacific and Atlantic Oceans major barriers, as well as the Great Lakes. Distance was measured either due west or east from the counting station, depending on the location of the diversion line. We also measured length of rivers that occurred inside the buffer area (RIVERS).

All counting stations in the United States (Table 1), including the counting stations we established in Arizona, were separated into spring and fall.  Average number of raptors counted at each station for each season (spring and fall) and year (2014/2015 and 2015/2016 was log transformed to obtain a more normal distribution (AVG_RAPTORS) (Ramsey and Schafer 2002). We used stepwise multiple linear regression models, generated in R (R Core Team 2013, Mass and Leaps libraries), to relate the average number of raptors counted to the seven physical metrics. Models were created for the entire United States as well as the Pacific and Central Flyway to account for physical and ecological features that might be unique to the western United States.

## 2.5 Results

The physical model for the entire United States in spring accounted for substantial variation in the data (adjusted $R^2$=0.73; Table 4). Raptor counts in the spring were negatively related to distance from a diversion line (BARRIER) and distance an animal could move within the predominant land cover type (GYRATE_NLCD) (Figure 2), and positively related to the proportion of the buffer area in the predominant land cover type (PLAND) (Figure 1) and distance an animal could move within the elevation class at and above the counting station (GYRATE_DEM) (Figure 3, 4). The fall physical model for the entire United States included more counting stations and accounted for considerably less variation in the data (adjusted $R^2$= 0.13; Table 5) than the spring model, but included similar variables. Raptor counts in the fall were negatively related to distance from a diversion line (BARRIER) and proportion of the buffer area in the predominant land cover type (PLAND), and positively related to distance an animal could move within the elevation class at and above the counting station (GYRATE_DEM) and length of rivers inside the buffer area (RIVERS).

The multiple linear regression model for the Pacific and Central Flyways for spring accounted for substantial variation in raptor counts among counting stations (adjusted $R^2$ = 0.76; Table 6). Raptor counts in the spring were negatively related to distance from a diversion line (BARRIER) and distance an animal could move within the predominant land cover type (GYRATE_NLCD), and positively related to distance an animal could move within the elevation class at and above the counting station (GYRATE_DEM). The fall regression model for the Pacific and Central Flyways included more counting stations ($n$ = 23), and accounted for about half the variation in raptor counts among counting stations (Table 7) (adjusted $R^2$= 0.51; F-Statistic = 8.70. 3 and 19 DF, $P$ = 0.001). Raptor counts during this period were negatively related to distance from a diversion line (BARRIER), the probability that two randomly chosen pixels within the buffer area were not in the same patch of elevation class (DIVISION_DEM), and the proportion of the buffer area comprised of the predominant land cover type within a 500 m radius of the counting station (PLAND).

## 2.6 Discussion

Physical regression models for the entire United States in both spring and fall suggested that the number of raptors observed at counting stations was negatively related to distance the counting station was from a diversion line. Diversion lines often are large bodies of water, and can act as funnels and concentrate migrating raptors because most raptors are hesitant to fly over them. During fall migration, juvenile raptors are especially susceptible to wind drift and are pushed east to the Atlantic coastline by westerly winds (Thorup et al. 2003). Some adults are influenced by wind drift as well and this funneling effect is apparent at counting stations situated near large bodies of water, such as the Detroit River counting station, located on Lake Erie, the Corpus Christi counting station, located near the Gulf of Mexico, and the Guana Preserve counting station, located on the Atlantic Ocean. The counting stations we established in central and southeastern Arizona are far from any body of water that would influence raptor movements or create a large funneling effect.

Both fall and spring physical regression models for the entire United States also suggested that the number of raptors at counting stations was positively related to the continuity of elevation at and above the counting station. Continuous topographic features, such as a line of mountains, can concentrate raptor movements either as leading lines or because of the updrafts associated with them. The Appalachian Mountains in the eastern United States are an example of where continuous elevation, oriented generally north to south, promote high rates of raptor migration. Although not all the counts in the Appalachian Mountains are in the top 10% for the

United States, raptor passage rates are consistently high through the area year-to-year (Allen et al. 1996, Therrien et al. 2012). In juxtaposition, the mountains of central and southeastern Arizona are discontinuous and are called “sky islands” because they are physically separate from each other. There is also a “sea” of desert that occurs between each range of mountains, making them isolated from one another and different in plant composition (Boyd 2002). The lack of continuity as a line of mountains may contribute to the relatively low concentration of raptors we observed at our counting stations. The discontinuous nature of most mountain ranges in the west, with the exception of the Rockies, could also attribute to the low number of raptors counted generally in the western United States.

Continuity of the type of land cover in which the counting station is located also could be a factor that promotes high rates of passage because raptors may seek to fly over a particular environment that provides suitable stop-over sites (Mojica et al. 2008). Measures of continuity of land cover were included in both the fall and spring physical regression models for the entire United States, but were either inconsistent in their influence in both models (PLAND was positively related to raptor counts in spring, but negatively related in fall), or were negatively associated with raptor counts (e.g., GYRATE_NCLD in the spring model). It is difficult to explain these contradictory relationships, but it could be related to the fact that the predominant land cover type in the immediate vicinity of the counting station (i.e., a 500 m radius) was not always the predominant land cover type within the larger buffer area in which we made our measurements. Because we used average count of all raptors, not individual species, isolating specific land cover types would have been inappropriate. Therefore, we chose to measure the continuity of the land cover type directly surrounding the counting station.

The physical regression models for the Pacific and Central Flyways in fall and spring were similar to the models produced for the entire United States. In the fall, average counts were negatively related to distance from a diversion barrier, continuity of elevation, and continuity of land cover type. In spring, average raptor counts were negatively related to distance from a diversion barrier and continuity of land cover type, but positively related to continuity of elevation. The similarity in models between the entire United States and the Pacific and Central Flyways suggest the models are appropriate for predicting raptor migration rates across the United States.

2.7 List of Tables and Figures

Table 1. Average number of raptors observed per hour at counting stations across the United States in fall and spring combined, 2014 – 2016 (* denotes counting stations in central and southeastern Arizona).

| Counting Station | UTM Zone | State | Season | Avg. Raptors |
|---|---|---|---|---|
| Pinaleno Mtns | 12 | AZ | Fall/Spring | 1.2 |
| Pinal Mtns | 12 | AZ | Fall/Spring | 1.4 |
| Dragoon Mtns | 12 | AZ | Fall/Spring | 1.4 |
| Santa Cruz River | 12 | AZ | Fall/Spring | 1.7 |
| Mule Mtns | 12 | AZ | Fall/Spring | 1.9 |
| Dinosaur Ridge | 13 | CO | Spring | 2.0 |
| Bradshaw #1 Mtns | 12 | AZ | Fall/Spring | 2.1 |
| Bradshaw #2 Mtns | 12 | AZ | Fall/Spring | 2.4 |
| Pinnacle Rock | 19 | MA | Fall | 2.5 |
| Chiricahua #2 Mtns | 12 | AZ | Fall/Spring | 3.1 |
| San Pedro River | 12 | AZ | Fall/Spring | 3.2 |
| Marine Nature Area | 18 | NY | Fall | 3.3 |
| Chelan Ridge | 10 | WA | Fall | 3.4 |
| Tussey Mountain | 18 | PA | Spring | 4.7 |
| Kittatiny Mountain | 18 | NJ | Fall | 5.2 |
| Plum Island | 19 | MA | Spring | 5.8 |
| Chiricahua #1 Mtns | 12 | AZ | Fall/Spring | 5.8 |
| Fire Island | 18 | NY | Fall | 5.9 |
| Commissary Ridge | 12 | WY | Fall | 6.0 |
| Illinois Beach State Park | 16 | IL | Fall | 6.1 |
| Cumberland Gap | 17 | MD | Fall | 7.4 |
| Tubac HW | 12 | AZ | Spring | 7.6 |
| Pilgrim Heights | 19 | MA | Spring | 7.6 |
| Rose Tree Park | 18 | PA | Fall | 7.7 |

| | | | | |
|---|---|---|---|---|
| Turkey Point | 18 | MD | Fall | 8.0 |
| Greene Valley Forest Preserve | 16 | IL | Fall | 8.2 |
| MPG Ranch | 12 | MT | Fall | 8.2 |
| Franklin Moutain | 18 | NY | Fall | 8.8 |
| Bonney Butte | 10 | OR | Fall | 8.9 |
| Cadillac Mountain | 19 | ME | Fall | 8.9 |
| Allegheny Front | 17 | PA | Fall | 9.0 |
| Hitchcock Nature Center | 15 | IA | Fall | 9.3 |
| Bradbury Mountain SP | 19 | ME | Spring | 9.7 |
| Lenoir Wildlife Sanctuary | 18 | NY | Fall | 9.9 |
| Second Mountain | 18 | PA | Fall | 10.4 |
| Stone Mountain | 18 | PA | Fall | 10.4 |
| Jewel Basin | 12 | MT | Fall | 10.4 |
| Jacks Mountain | 18 | PA | Fall | 10.6 |
| Washington Monument SP | 18 | MD | Fall | 11.0 |
| Lipan Point | 12 | AZ | Fall | 11.1 |
| Manzano Mountains | 12 | NM | Fall | 11.3 |
| Ashland Nature Center | 18 | DE | Fall | 13.2 |
| Sunrise Mountain | 18 | NJ | Fall | 13.2 |
| Guana Preserve | 17 | FL | Fall | 13.4 |
| Lighthouse Point | 18 | CT | Fall | 13.5 |
| Hanging Rock Tower | 17 | WV | Fall | 13.6 |
| Mahogany Rock | 17 | NC | Fall | 13.7 |
| College Creek | 18 | VA | Fall | 14.0 |
| Rocky Face Mt. Rec Area | 17 | NC | Fall | 14.2 |
| Putney Mountain | 18 | VT | Fall | 14.3 |
| Carter Hill Observatory | 19 | NH | Fall | 14.4 |
| Bake Oven Knob | 18 | PA | Fall | 15.0 |
| Bethany HW | 15 | MN | Fall | 15.2 |

| | | | | |
|---|---|---|---|---|
| Militia Hill | 18 | PA | Fall | 15.2 |
| Chimney Rock | 18 | NJ | Fall | 16.0 |
| Fort Sheridan | 16 | IL | Fall | 16.1 |
| Hook Mountain | 18 | NY | Fall | 16.2 |
| Hawk Mountain Sanctuary | 18 | PA | Fall | 16.3 |
| Montclair HW | 18 | NJ | Fall | 16.3 |
| Tuscacora Summit | 18 | PA | Fall | 16.7 |
| Boothe Memorial Park | 18 | CT | Fall | 16.7 |
| Harpswell Peninsula | 19 | ME | Fall | 17.2 |
| Little Round Top | 19 | NH | Fall | 17.2 |
| Yaki Point | 12 | AZ | Fall | 17.3 |
| Cape Henlopen | 18 | DE | Fall | 17.4 |
| Council Cap | 18 | PA | Fall | 17.9 |
| Quaker Ridge | 18 | CT | Fall | 18.1 |
| Brockway Mountain | 16 | MI | Spring | 18.1 |
| Wildcat Ridge | 18 | NJ | Fall | 18.4 |
| Harvey's Knob | 17 | VA | Fall | 18.9 |
| Racoon Ridge | 18 | NJ | Fall | 19.9 |
| S.C. Coastal Hwy | 17 | SC | Fall | 20.0 |
| State Line HW | 18 | NJ | Fall | 20.0 |
| Blueberry Hill | 18 | MA | Fall | 21.3 |
| Little Gap | 18 | PA | Fall | 21.5 |
| Whitefish Point | 16 | MI | Spring | 22.1 |
| Caesar's Head | 17 | SC | Fall | 22.2 |
| Waggoner's Gap | 18 | PA | Fall | 23.0 |
| Port Huron | 17 | MI | Spring | 23.5 |
| Fort Smallwood | 18 | MD | Fall | 23.5 |
| Summitville | 18 | NY | Fall | 23.7 |
| Mount Peter | 18 | NY | Fall | 24.3 |

| | | | | |
|---|---|---|---|---|
| Eagle Valley | 15 | WI | Fall | 25.7 |
| Belmont Valley | 17 | VA | Fall | 26.0 |
| Barre Falls | 18 | MA | Fall | 27.1 |
| Rockfish Gap | 17 | VA | Fall | 30.2 |
| Pack Monadock | 19 | NH | Fall | 30.8 |
| Mendota Fire Tower | 17 | VA | Fall | 31.3 |
| Scott's Mountain | 18 | NJ | Fall | 31.5 |
| Kiptopeke HW | 18 | VA | Fall | 34.6 |
| Middle School | 18 | CT | Fall | 35.5 |
| Cape May | 18 | NJ | Fall | 37.5 |
| Snicker's Gap | 18 | VA | Fall | 39.3 |
| Shatterack Mountain | 18 | MA | Fall | 39.4 |
| Cromwell Valley Park | 18 | MD | Fall | 40.0 |
| Pilot Mountain SP | 17 | NC | Fall | 44.3 |
| Johnnycake Mountain | 18 | CT | Fall | 45.4 |
| Wachusett Mountain | 19 | MA | Fall | 49.0 |
| Grandfather Mountain | 17 | NC | Fall | 49.1 |
| Botsford Hill | 18 | CT | Fall | 53.0 |
| Clarry Hill | 19 | ME | Fall | 58.8 |
| Hamburg HW | 17 | NY | Fall | 59.3 |
| West Skyline | 15 | MN | Fall | 61.8 |
| Florida Keys | 17 | FL | Fall | 68.1 |
| Borrego Valley | 11 | CA | Spring | 68.2 |
| Derby Hill | 18 | NY | Spring | 78.4 |
| Goshute Mountains | 11 | NV | Fall | 80.6 |
| Chesnut Hill | 18 | CT | Fall | 81.6 |
| Mill Creek Road | 16 | AL | Fall | 82.1 |
| Mackinac Straits | 16 | MI | Spring | 83.1 |
| Hawk Ridge | 15 | MN | Fall | 87.1 |

| | | | | |
|---|---|---|---|---|
| Smith Point | 15 | TX | Fall | 92.0 |
| Good Hill | 18 | CT | Fall | 93.1 |
| Presque Island | 17 | PA | Spring | 95.4 |
| Ripley Hawkwatch | 17 | NY | Spring | 114.1 |
| Santa Ana Refuge | 14 | TX | Spring | 114.8 |
| Port Crescent Hawkwatch | 17 | MI | Spring | 139.2 |
| Booth Hill | 18 | CT | Fall | 149.6 |
| Broadwing | 18 | PA | Fall | 152.1 |
| Detroit River | 17 | MI | Fall | 379.0 |
| Bentsen Rio Grande | 14 | TX | Fall | 557.7 |
| Corpus Christi | 14 | TX | Fall | 696.6 |

Table 2. United States counting stations, including city, state, north latitude and west longitude (in meters), and elevation (m) (*denotes counting stations established in Arizona).

| Counting Station | City | State | Latitude | Longitude | Elevation |
|---|---|---|---|---|---|
| Allegheny Front | Central City | PA | 40.08142 | 78.72783 | 832 |
| Ashland Nature Center | Hockessin | DE | 39.79714 | 75.66161 | 75 |
| Bake Oven Knob | Germansville | PA | 40.74883 | 75.73358 | 482 |
| Barre Falls | Barre | MA | 42.43167 | 72.02583 | 261 |
| Belmont Valley | Charlottesville | VA | 38.02132 | 78.48311 | 135 |
| Bentsen Rio Grande | Mission | TX | 26.16889 | 98.38056 | 34 |
| Bethany HW | Mankato | MN | 44.16611 | 93.99083 | 304 |
| Blueberry Hill | Granville | MA | 42.09583 | 72.92500 | 441 |
| Bonney Butte | Madras | OR | 45.26306 | 121.59194 | 1673 |
| Booth Hill | West-Hartland | CT | 42.01972 | 72.96694 | 398 |
| Boothe Memorial Park | Stratford | CT | 41.23560 | 73.11051 | 40 |
| Borrego Valley | Borrego Springs | CA | 33.29732 | 116.36680 | 200 |
| Botsford Hill | Bridgewater | CT | 41.52472 | 73.33522 | 221 |
| Bradbury Mountain SP | Pownal | ME | 43.89639 | 70.19056 | 42 |
| Bradshaw #1 Mtns* | Prescott | AZ | 34.43063 | 112.38910 | 2209 |
| Bradshaw #2 Mtns* | Prescott | AZ | 34.48352 | 112.37415 | 1868 |
| Broadwing | Pipersville | PA | 40.44563 | 75.13922 | 120 |
| Brockway Mountain | Copper Harbor | MI | 47.46410 | 87.96938 | 405 |
| Cadillac Mountain | Bar Harbor | ME | 44.35624 | 68.22461 | 380 |
| Caesar's Head | Caesar's Head | SC | 35.10556 | 82.62806 | 970 |
| Cape Henlopen | Lewes | DE | 38.78417 | 75.08417 | -1 |
| Cape May | Cape May | NJ | 38.93258 | 74.95800 | 2 |
| Carter Hill Observatory | Concord | NH | 43.23453 | 71.60994 | 218 |
| Chelan Ridge | Pateros | WA | 48.02022 | 120.09313 | 1678 |
| Chesnut Hill | Litchfield | CT | 41.73397 | 73.17069 | 360 |
| Chimney Rock | Martinsville | NJ | 40.58222 | 74.55622 | 61 |
| Chiricahua #1 Mtns* | Sunizona | AZ | 32.00846 | 109.31245 | 2097 |
| Chiricahua #2 Mtns* | Sunizona | AZ | 31.91028 | 109.27268 | 2510 |
| Clarry Hill | Union | ME | 44.19611 | 69.32167 | 197 |
| College Creek | Williamsburg | VA | 37.21667 | 76.70278 | 0 |
| Commissary Ridge | Hamsfork | WY | 42.02472 | 110.58944 | 2713 |

| | | | | | |
|---|---|---|---|---|---|
| Corpus Christi | Corpus Christi | TX | 27.86556 | 97.64278 | 19 |
| Council Cap | Wapwallopen | PA | 41.07669 | 76.12147 | 302 |
| Cromwell Valley Park | Baltimore | MD | 39.41627 | 76.54955 | 69 |
| Cumberland Gap | Cumberland | MD | 39.66922 | 78.77873 | 409 |
| Derby Hill | Mexico | NY | 43.52750 | 76.23944 | 93 |
| Detroit River | Brownstown | MI | 42.07918 | 83.19369 | 175 |
| Dinosaur Ridge | Denver | CO | 39.70082 | 105.20019 | 1951 |
| Dragoon Mtns* | Sunsites | AZ | 31.86633 | 109.95103 | 1865 |
| Eagle Valley | Glen Haven | WI | 42.79167 | 91.07500 | 186 |
| Fire Island | Islip | NY | 40.63705 | 73.22489 | 1 |
| Florida Keys | Little Krawl Key | FL | 24.74944 | 80.98444 | 0.4 |
| Fort Sheridan | Lake Forest | IL | 42.22283 | 87.81198 | 199 |
| Fort Smallwood | Pasadena | MD | 39.16333 | 76.47694 | 2 |
| Franklin Mountain | Oneonta | NY | 42.42539 | 75.04694 | 594 |
| Good Hill | Woodbury | CT | 41.55317 | 73.25983 | 291 |
| Goshute Mountains | West Wendover | NV | 40.42430 | 114.27103 | 2743 |
| Grandfather Mountain | Linville | NC | 36.09439 | 81.83313 | 1590 |
| Greene Valley F.P. | Naperville | IL | 41.73056 | 88.07889 | 219 |
| Guana Preserve | Ponte Vedra Beach | FL | 30.11667 | 81.34528 | 6 |
| Hamburg HW | Hamburg | NY | 42.75583 | 78.86167 | 204 |
| Hanging Rock Tower | Waiteville | WV | 37.47361 | 80.42222 | 669 |
| Harpswell Peninsula | Harpswell | ME | 43.75130 | 70.03238 | 0 |
| Harvey's Knob | Roanoke | VA | 37.44525 | 79.72683 | 768 |
| Hawk Mountain Sanct. | Kempton | PA | 40.64158 | 75.99153 | 449 |
| Hawk Ridge | Duluth | MN | 46.84722 | 92.03194 | 350 |
| Hitchcock Nat. Cen. | Honey Creek | IA | 41.41324 | 95.85865 | 395 |
| Hook Mountain | Rockland Lake | NY | 41.12089 | 73.91833 | 205 |
| Illinois Beach S.P. | Zion | IL | 42.46698 | 87.80511 | 179 |
| Jacks Mountain | Lewistown | PA | 40.54347 | 77.75703 | 552 |
| Jewel Basin | Bigfork | MT | 48.15520 | 113.93294 | 2155 |
| Johnnycake Mountain | Burlington | CT | 41.75469 | 72.99442 | 350 |
| Kiptopeke HW | Cape Charles | VA | 37.16378 | 75.97667 | 9 |
| Kittatiny Mountain | Crandon Lakes | NJ | 41.15067 | 74.84180 | 392 |
| Lenoir Wildlife Sanct. | Yonkers | NY | 40.97523 | 73.88323 | 95 |
| Lighthouse Point | New Haven | CT | 41.24986 | 72.90142 | 6 |

| | | | | | |
|---|---|---|---|---|---|
| Lipan Point | Grand Canyon | AZ | 36.03306 | 111.85333 | 2231 |
| Little Gap | Danielsville | PA | 40.80589 | 75.54119 | 438 |
| Little Round Top | Bristol | NH | 43.57903 | 71.73069 | 289 |
| Mackinac Straits | Mackinaw City | MI | 45.77743 | 84.76505 | 196 |
| Mahogany Rock | Sparta | NC | 36.44131 | 81.09529 | 1045 |
| Manzano Mountains | Mountainair | NM | 34.70417 | 106.41111 | 2829 |
| Marine Nature Area | Oceanside | NY | 40.62324 | 73.62423 | 1 |
| Mendota Fire Tower | Mendota | VA | 36.73056 | 82.30056 | 902 |
| Middle School | Torrington | CT | 41.83494 | 73.07447 | 340 |
| Militia Hill | Fort Washington | PA | 40.12062 | 75.22277 | 77 |
| Mill Creek Road | Dora | AL | 33.73594 | 87.01692 | 160 |
| Montclair HW | Montclair | NJ | 40.84664 | 74.21294 | 166 |
| Mount Peter | Warwick | NY | 41.24545 | 74.28775 | 367 |
| MPG Ranch | Florence | MT | 46.70346 | 113.98714 | 1702 |
| Mule Mtns* | Bisbee | AZ | 31.47179 | 109.95071 | 2083 |
| Pack Monadock | Peterborough | NH | 42.86306 | 71.87833 | 675 |
| Pilgrim Heights | North Truro | MA | 42.05525 | 70.13281 | 2 |
| Pilot Mountain SP | Surry County | NC | 36.34222 | 80.47861 | 650 |
| Pinal Mtns* | Globe | AZ | 33.28473 | 110.83268 | 2303 |
| Pinaleno Mtns* | Safford | AZ | 32.65639 | 109.86093 | 2770 |
| Pinnacle Rock | Malden | MA | 42.43944 | 71.07667 | 32 |
| Plum Island | Newburyport | MA | 42.79167 | 70.80667 | 1 |
| Port Crescent HW | Port Crescent | MI | 44.00019 | 83.06694 | 177 |
| Port Huron | Lakeport | MI | 43.10086 | 82.49947 | 186 |
| Presque Island | Erie | PA | 42.10856 | 80.15328 | 201 |
| Putney Mountain | Putney | VT | 43.00443 | 72.59560 | 511 |
| Quaker Ridge | Greenwich | CT | 41.09711 | 73.68867 | 154 |
| Raccoon Ridge | Blairstown | NJ | 41.01486 | 75.04256 | 477 |
| Ripley Hawkwatch | Ripley | NY | 42.30973 | 79.64955 | 191 |
| Rockfish Gap | Waynesboro | VA | 38.02958 | 79.85844 | 558 |
| Rocky Face Mtn R.A. | Hiddendite | NC | 35.97222 | 81.10917 | 544 |
| Rose Tree Park | Media | PA | 39.93964 | 75.39210 | 99 |
| S.C. Coastal Hwy | Awenda | SC | 32.91681 | 79.70578 | 3 |
| San Pedro River* | Fairbank | AZ | 31.72553 | 110.19444 | 1167 |
| Santa Ana Refuge | Alamo | TX | 26.08247 | 98.13897 | 28 |

| | | | | | |
|---|---|---|---|---|---|
| Santa Cruz River* | Tucson | AZ | 32.40133 | 111.14611 | 631 |
| Scott's Mountain | Harmony Twnshp | NJ | 40.74186 | 75.10867 | 287 |
| Second Mountain | Ft. Indianatown | PA | 40.47275 | 76.62147 | 295 |
| Shatterack Mountain | Russell | MA | 42.18972 | 72.86389 | 126 |
| Smith Point | Smith Point | TX | 29.52611 | 94.76583 | 4 |
| Snicker's Gap | Leesburg | VA | 39.11550 | 77.84694 | 329 |
| State Line HW | Alpine | NJ | 40.98972 | 73.90611 | 119 |
| Stone Mountain | Allensville | PA | 40.57178 | 77.82636 | 641 |
| Summitville | Summitville | NY | 41.62139 | 74.45111 | 166 |
| Sunrise Mountain | Branchville | NJ | 41.21813 | 74.72045 | 498 |
| Tubac HW | Tubac | AZ | 31.60970 | 111.04310 | 973 |
| Turkey Point | Aberdeen | MD | 39.45215 | 76.00753 | 24 |
| Tuscacora Summit | Fort London | PA | 39.91464 | 77.95839 | 650 |
| Tussey Mountain | State College | PA | 40.71053 | 77.90458 | 617 |
| Wachusett Mountain | Princeton | MA | 42.48917 | 71.88750 | 608 |
| Waggoner's Gap | Harrisburg | PA | 40.27719 | 77.27603 | 462 |
| Washington Mon. S.P. | Boonsboro | MD | 39.54689 | 77.60993 | 299 |
| West Skyline | Duluth | MN | 46.77563 | 92.12424 | 347 |
| Whitefish Point | Paradise | MI | 47.41611 | 87.65222 | 184 |
| Wildcat Ridge | Hibernia | NJ | 40.94719 | 74.47211 | 306 |
| Yaki Point | Grand Canyon | AZ | 36.05861 | 112.08389 | 2211 |

Table 3. Variables used to describe landscape attributes of stations where raptors were counted during migration in fall and spring, 2014-2016.

| Metric | Description | Values |
|---|---|---|
| AVG_RAPTORS | Average number of raptors per hour | AVG_RAPTORS ≥0, without limit |
| BARRIER | Distance to nearest major coastline, either due west or east from count station (kilometers) | BARRIER ≥ 0, without limit (km) |
| RIVERS | Length of rivers within buffer (kilometers) | RIVERS ≥ 0, without limit (km) |
| AI_NLCD | Aggregation index for corresponding land cover type | 0 ≤ AI_NLCD ≤ 100 |
| GYRATE_NLCD | Radius of gyration measure for corresponding land cover type (meters) | GYRATE_NLCD ≥0, without limit (m) |
| DIVISION_DEM | Division index for elevation | 0 ≤ DIVISION_DEM <1 |
| GYRATE_DEM | Radius of gyration measure for corresponding elevation (meters) | GYRATE_DEM ≥ 0, without limit (m) |
| PLAND | Proportion of landscape comprised of corresponding land cover type | 0 < PLAND ≤ 100 |

Table 4. Stepwise multiple linear regression model relating counts of raptors during spring migration (2015 – 2016) and characteristics of the counting stations across the United States ($n$ = 26). Adjusted $R^2$ = 0.73; F-statistic = 17.67, 4 and 21 DF; $P$-value = 1.73e-06.

| Coefficient | Estimate | *P* |
|---|---|---|
| Intercept | 9.211e-01 | 0.0007 |
| BARRIER | -9.196e-04 | 0.0015 |
| GYRATE_NLCD | -2.321e-05 | 0.0116 |
| GYRATE_DEM | 9.864e-06 | 0.0121 |
| PLAND | 7.366e-03 | 0.1826 |

Table 5. Stepwise multiple linear regression model relating counts of raptors during fall migration (2014 – 2015) and characteristics of the counting stations across the United States ($n$ = 106). Adjusted $R^2$ = 0.13; F-statistic = 4.934, 4 and 101 DF; $P$-value = 1.127e-03.

| Coefficient | Estimate | *P* |
|---|---|---|
| Intercept | 1.140e+0 | 3.57e-10 |
| BARRIER | -3.905e-04 | 0.0152 |
| RIVERS | 8.953e-04 | 0.0453 |
| GYRATE_DEM | 3.636e-05 | 0.1089 |
| PLAND | -4.104e-03 | 0.0560 |

Table 6. Stepwise multiple linear regression model relating counts of raptors during spring migration (2015 – 2016) and physical characteristics of the counting stations in the Pacific and Central Flyways ($n$ = 14). Adjusted $R^2$ = 0.76; F-statistic = 11.54, 4 and 9 DF; $P$-value = 0.001.

| Coefficient | Estimate | *P* |
|---|---|---|
| Intercept | -7.973e-01 | 0.588 |
| BARRIER | -1.059e-03 | 0.005 |
| GYRATE_NLCD | -1.937e-05 | 0.004 |
| GYRATE_DEM | 1.494e-05 | 0.003 |

Table 7. Stepwise multiple linear regression model relating counts of raptors during fall migration (2014 – 2015) and physical characteristics of the counting stations in the Pacific and Central Flyways ($n$ = 23). Adjusted $R^2$ = 0.51; F-statistic = 8.70, 3 and 19 DF; $P$-value = 0.001.

| Coefficient | Estimate | *P* |
|---|---|---|
| Intercept | 2.2802 | 0.0001 |
| BARRIER | -0.0004 | 0.10 |
| DIVISION_DEM | -0.7979 | 0.001 |
| PLAND | -0.0125 | 0.004 |

Figure 1. Example of land cover type reclassification used for analysis to measure the degree of continuity of land cover type surrounding the counting station (2014-2016, Goshute Mountains, West Wendover NV).

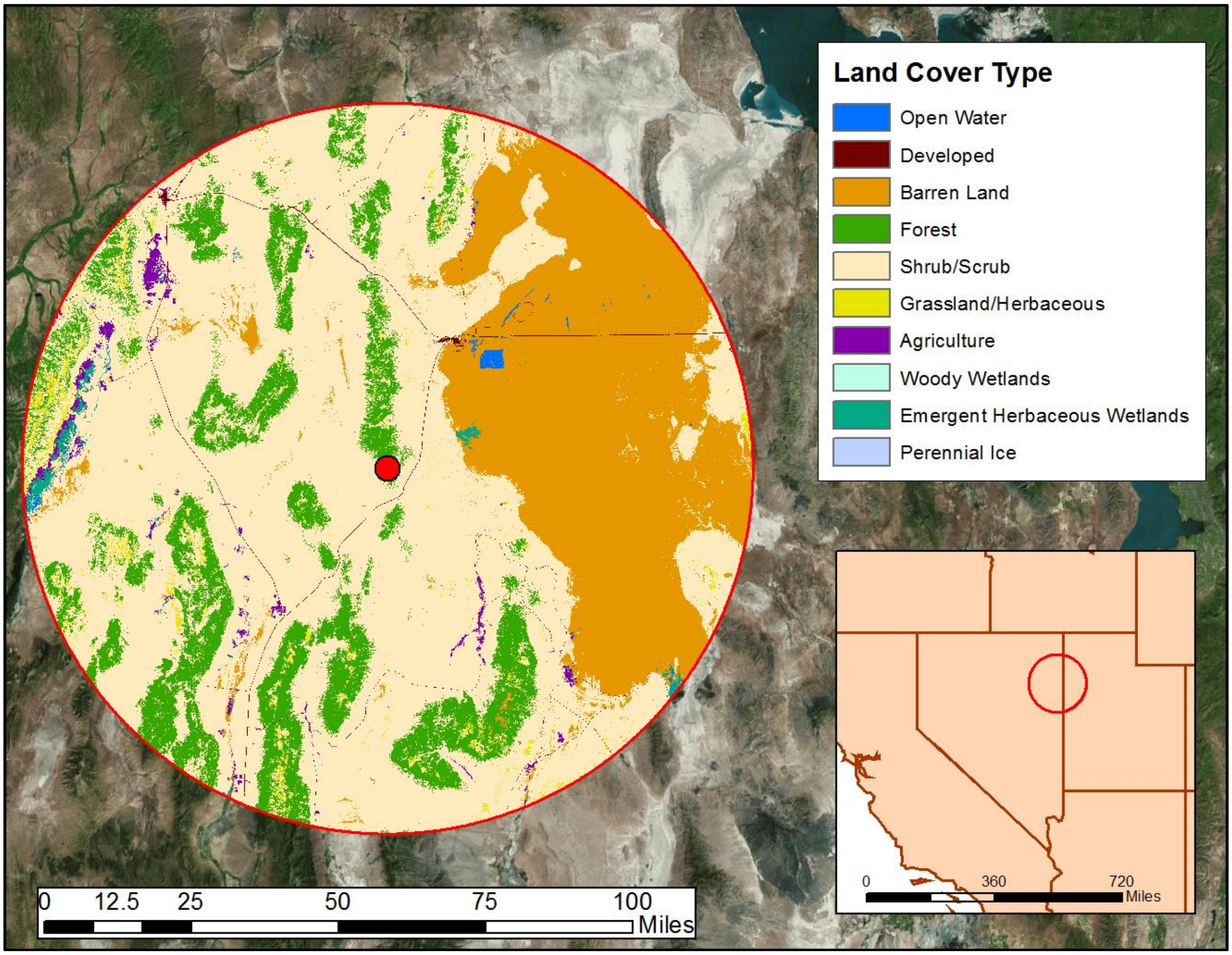


Figure 2. Example of land cover type reclassification used for analysis to measure the degree of continuity of land cover type surrounding the counting station (2014-2016, Allegheny Front, Central City PA).

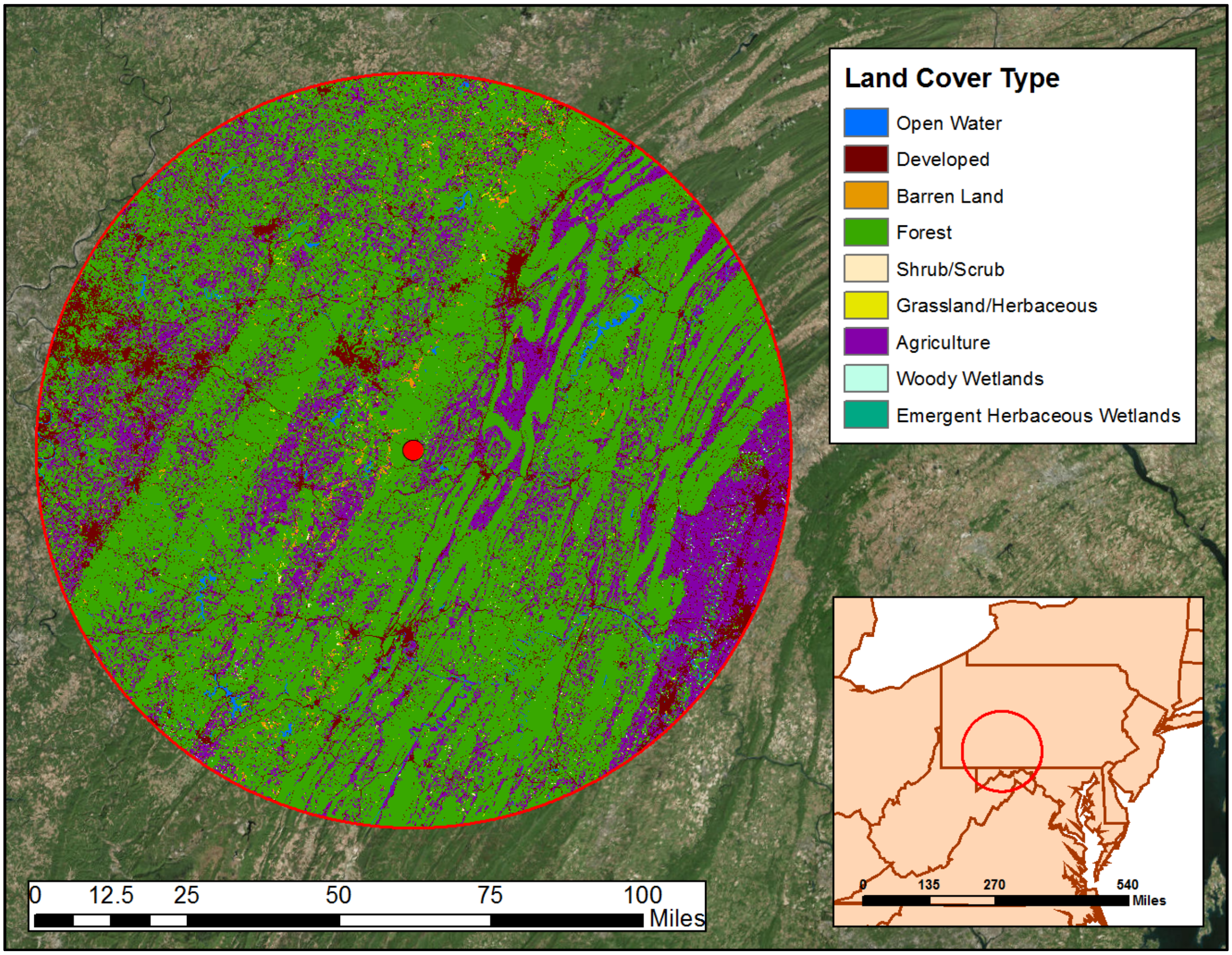


Figure 3. Example of elevation reclassification used for analysis to measure the degree of continuity of elevation surrounding the counting station (2014-2016, Hanging Rock, Waiteville WV).

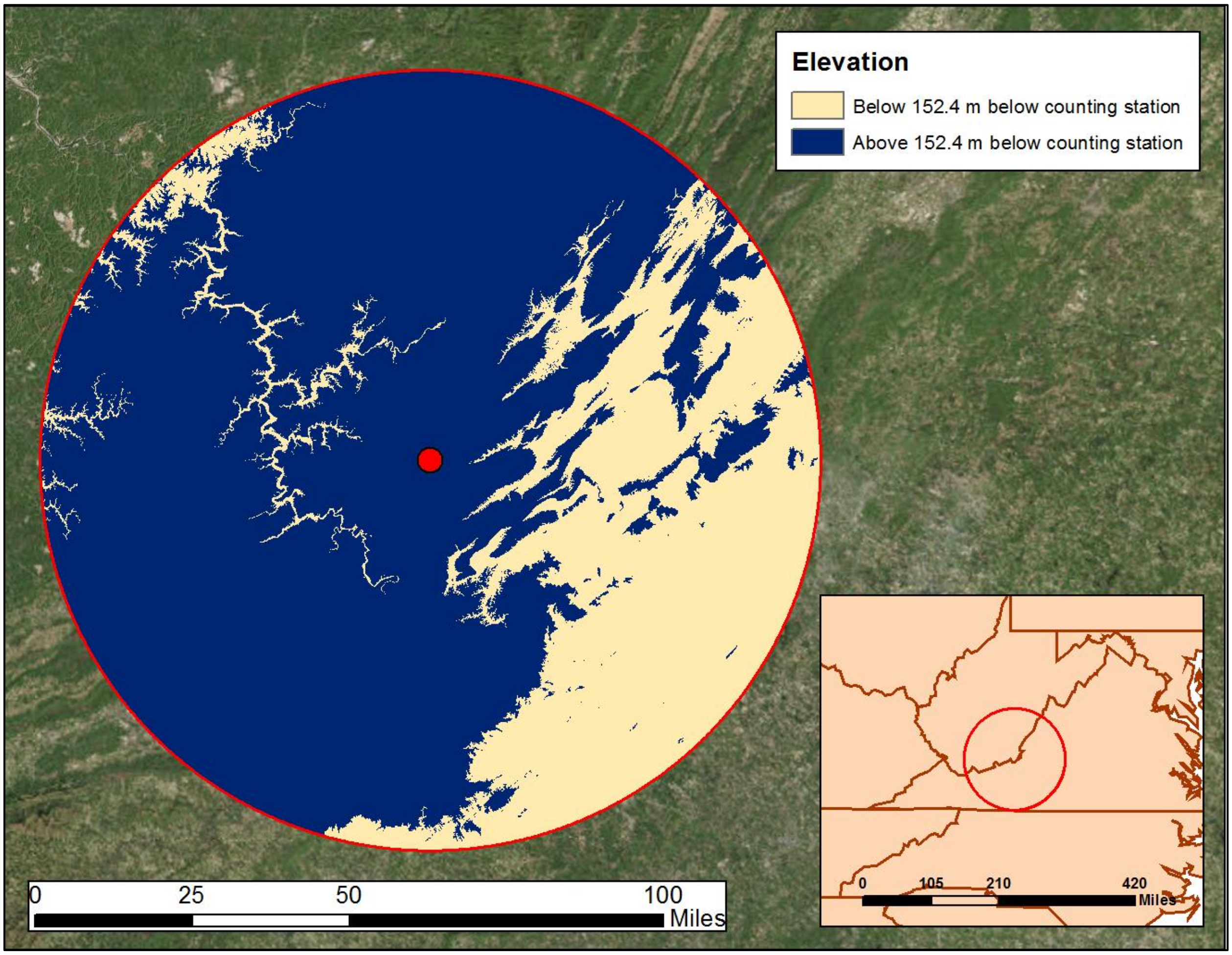
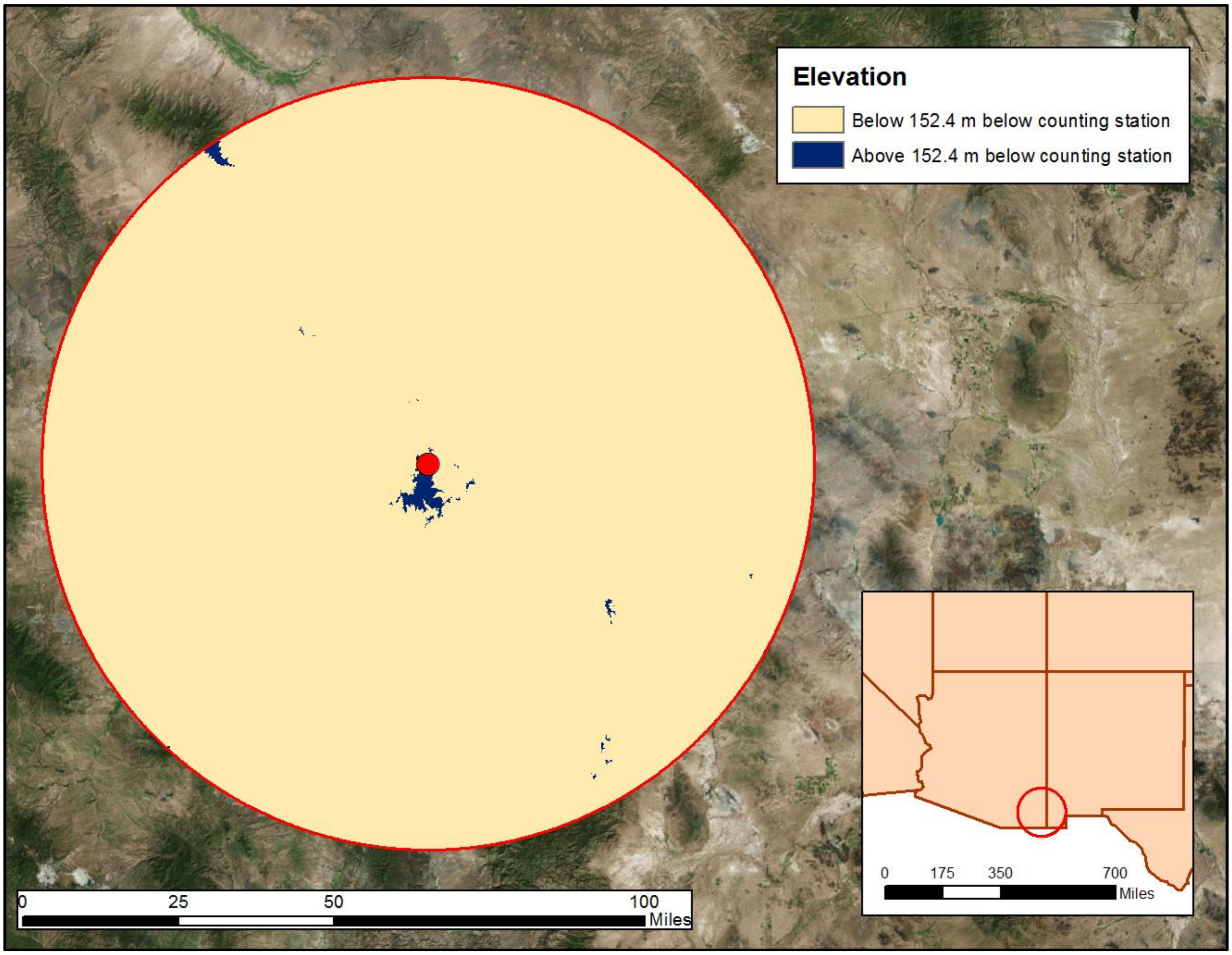


Figure 4. Example of elevation reclassification used for analysis to measure the degree of continuity of elevation surrounding the counting station (2014-2016, Chiricahua #2 Mountains, Sunizona AZ).



2.8 Literature Cited


Allen, P.E., L.J. Goodrich, and K.L. Bildstein. 1996. Within- and among- year effects of cold fronts on migrating raptors at Hawk Mountain, Pennsylvania, 1934-1991. *The Auk*113(2): 329-338.

Baird, J., and I.C.T. Nisbet. 1960. Northward fall migration on the Atlantic Coast and its relation to offshore drift. *The Auk* 77 (2): 119-149.

Bednarz, J.C., D. Klem Jr., L.J. Goodrich, and S.E. Senner. 1990. Migration counts of raptors at Hawk Mountain, Pennsylvania, as indicators of population trends, 1934-1986. *The Auk* 107: 96-109.

Bildstein, K.L. 2006. Migrating Raptors of the World: Their Ecology and Conservation. Cornell University Press, Ithaca, New York.

Boyd, A. 2002. Morphological analysis of sky island populations of Macromeria viridflora (Boraginaceae). *Systematic Botany* 27(1): 116-126.

Chavez-Ramirez, F., G.P. Vose, and A. Tennant. 1994. Spring and fall migration of peregrine falcons from Padre Island, Texas. *The Wilson Bulletin* 106(1): 138-145.

"Downloads | Natural Earth." Made with Natural Earth, www.naturalearthdata.com/downloads/. Accessed 30 Mar. 2017

ESRI 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

Farmer, C.J., D.J.T. Hussell, and D. Mizrahi. 2007. Detecting population trends in migratory birds of prey. *The Auk* 124(3): 1047-1062.

Goodrich, L.J. and J. Smith. 2008. Raptor Migration Geography in North America. Pages 37-150 in State of North American Birds of Prey (K. Bildstein, J. Smith, E. Ruelas-Inzunza, R. Veit, Eds.), Series in Ornithology, No. 3. American Ornithological Union, Washington D.C. and Nuttall Ornithological Club, Cambridge.

"HawkCount." HawkCount, Hawk Migration Association of North America, hawkcount.org/index.php. Accessed 15 May 2016.

Hoffman, S.W. and J.P. Smith. 2003. Population trends of migratory raptors in the western North America. *The Condor* 105(3): 397-413.

Hoffman, S.W., J.P. Smith, and T. Meehan. 2002. Breeding grounds, winter ranges, and migratory routes of raptors in the mountain west. *Journal of Raptor Research* 36: 97 110.

Homer, C.G., Dewitz, J.A., Yang, L., Jin, S., Danielson, P., Xian, G., Coulston, J., Herold, N.D., Wickham, J.D., and Megown, K., 2015, Completion of the 2011 National Land Cover Database for the conterminous United States-Representing a decade of land cover change Information. *Photogrammetric Engineering and Remote Sensing* 81(5): 345-354.

Klaassen R.H.G, M. Hake, R. Strandberg, and T. Alerstam. 2010. Geographical and temporal flexibility in the response to crosswinds by migrating raptors. *Proceedings of the Royal Society Biological Sciences* DOI: 10.1098/rspb.2010.2106.

Littlefield, C.D. and D.H. Johnson. 2013. Migration and habitat preferences of Swainson's hawks at an autumn stopover site in northwestern Texas. *Journal of Raptor Research* 47(1): 54-59.

Mandel, J.T., K.L. Bildstein, G. Bohrer, and D.W. Winkler. 2008. Movement ecology of migration in turkey vultures. *Proceedings of the National Academy of Sciences of the United States of America* 105(49): 19102-19107.

McGarigal, K., SA Cushman, and E Ene. 2012**.** FRAGSTATS v4: Spatial Pattern Analysis Program for Categorical and Continuous Maps. Computer software program produced by the authors at the University of Massachusetts, Amherst. Available at the following web site: http://www.umass.edu/landeco/research/fragstats/fragstats.html.

McHugh, Laura J. 2017. Assessment of Raptor Migration in the United States. The University of Arizona.

Mojica, E.K., J.M. Meyers, B.A. Millsap, and K.L. Haley. 2008. Migration of Florida sub-adult bald eagles. *The Wilson Jounral of Ornithology* 120(2): 304-310.

Moore, F. R, and D. Aborn. 2000. Mechanisms of en route habitat selection: how do migrants make habitat decisions during stopover? *Studies in Avian Biology* 20: 34-42.

Mueller, H.C., and D.D. Berger. 1967. Wind drift, leading lines, and diurnal migration. *Wilson Bulletin* 79:50-63.

Niles, L.J., J. Burger, and K.E. Clark. 1996. The influence of weather, geography, and habitat on migrating raptors on Cape May Peninsula. *The Condor* 98 (2): 382-394.

R Core Team. 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/.

Ramsey, F. L., and D.W. Schafer. 2002. The statistical sleuth: a course in methods of data analysis. 2nd ed. Boston: Brooks/Cole, Cengage Learning. Print.

Thierren, J.F., L.J. Goodrich, D.R. Barber, and K.L. Bildstein. 2012. A long-term database on raptor migration at Hawk Mountain Sanctuary, northeastern United States. *Ecology* 93(8): 1979.

Thorup, K., T. Alerstam, M. Hake, and N. Kjellén. 2003. Bird orientation: compensation for wind drift in migrating raptors is age dependent. *Proceedings: Biological Sciences* 270:S8-S11.

Wiltschko, W. and R. Wiltschko. 2005. Magnetic orientation and magnetoreception in birds and other animals. *Journal of Comparative Physiology* 191(8): 675-693.

Wiltschko, W., P. Weindler, and R. Wiltschko. 1998. Interaction of magnetic and celestial cues in the migratory orientation of passerines. *Journal of Avian Biology* 29(4): 606-617.